SCIENTIFIC DIALOGUES,

INTENDED FOR THE

INSTRUCTION AND ENTERTAINMENT

OF

YOUNG PEOPLE:

IN WHICH

THE FIRST PRINCIPLES

OF

NATURAL AND EXPERIMENTAL

PHILOSOPHY

ARE FULLY EXPLAINED.

VOL. V. OF OPTICS AND MAGNETISM.

"Conversation, with the habit of explaining the meaning of words, "and the structure of common domestic implements to children, is the "sure and effectual method of preparing the mind for the acquirement of "science." EDGEWORTH'S PRACTICAL EDUCATION.

BY THE REV. J. JOYCE.

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TO

ANNA LÆTITIA BARBAULD,

AND

JOHN AIKIN, M.D.

AUTHORS OF

"EVENINGS AT HOME,"

AND

OTHER ADMIRABLE WORKS

FOR

THE INSTRUCTION OF YOUNG PERSONS,

THE

FIFTH AND SIXTH VOLUMES

OF

SCIENTIFIC DIALOGUES

ARE RESPECTFULLY INSCRIBED

BY

THE AUTHOR.

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VOL. V.

OPTICS.

MAGNETISM.

CONVERSATION I.

INTRODUCTION.

Of Light—The Smallness of its Particles—Their Velocity—They move only in straight Lines.

CHARLES. When we were on the sea, you told us that you would explain the reason why the oar, which was straight when it lay in the boat, appeared crooked as soon as it was put into the water.

Tutor. I did: but it requires some previous knowledge before you can

comprehend the subject. It would afford you but little satisfaction to be told, that this deception was caused by the different degrees of *refraction* which take place in water and in air.

James. We do not know what you mean by the word refraction.

Tutor. It will therefore be right to proceed with caution; *refraction* is a term frequently used in the science of optics, and this science depends wholly on *light.*

James. What is light?

Tutor. It would, perhaps, be difficult to give a direct answer to your question, because we know nothing of the nature of light, but by the effects which it produces. In reasoning, however, on this subject, it is generally admitted that light consists

of inconceivably small particles; which are projected, or thrown off from a luminous body with great velocity, in all directions.

Charles. But how is it known that light is composed of small particles?

Tutor. There is no proof indeed that light is *material*, or composed of particles of matter, and therefore I said it was *generally*, not *universally*, admitted to be so: but if it is allowed that light is matter, then the particles must be small beyond all computation, or in falling on the eye they would infallibly blind us.

James. Does not the light come from the sun, in some such manner as it does from a candle?

Tutor. This comparison will answer our purpose; but there appears

to be a great difference between the two bodies: a candle, whether of wax or tallow, is soon exhausted: but philosophers never have been able to observe that the body of the sun is diminished by the light which it incessantly pours forth.

James. You say incessantly; but we see only during the hours of day.

Charles. That is because the part of the earth which we inhabit is turned away from the sun during the night: but our midnight is midday to some other parts of the earth.

Tutor. Right: besides you know the sun is not intended merely for the benefit of this globe, but it is the source of light and heat to six other planets, and eighteen moons belonging to them.

Charles. And you have not reck-

oned the four newly discovered little planets, which Dr. Herschel denominates *Asteroids*, but which are known by the names of Ceres Ferdinandea, Pallas, Juno, and Vesta.

Tutor. Well, then, the sun to these is the perpetual source of light, heat, and motion; and to more distant worlds it is a fixed star, and will appear to some as large as Arcturus, to others no larger than a star of the sixth magnitude, and to others it must be invisible, unless the inhabitants have the assistance of glasses, or are endowed with better eyes than ourselves.

James. Pray, Sir, how swift do you reckon that the particles of light move?

Tutor. This you will easily calculate when you know, that they are

only about eight minutes in coming from the sun.

Charles. And if you reckon the sun to be at the distance of ninety-five millions of miles from the earth, light proceeds at the rate, nearly, of twelve millions of miles in a minute, or 200,000 miles in a second of time. But how do you know that it travels so fast?

Tutor. It was discovered by M. Roemer, who observed that the eclipses of Jupiter's satellites took place about sixteen minutes later, if the earth were in that part of its orbit which is farthest from Jupiter than if it were in the opposite point of the heavens.

Charles. I understand this: the earth may sometimes be in a line between the sun and Jupiter; and at

other times the sun is between the earth and Jupiter; and therefore, in the latter case, the distance of Jupiter from the earth is greater than in the former, by the whole length of its orbit.

Tutor. In this situation the eclipse of any of the satellites is by calculation sixteen minutes later than it would be, if the earth were between Jupiter and the sun; that is, the light flowing from Jupiter's satellites is about sixteen minutes in travelling the length of the earth's orbit, or 190 millions of miles.

James. It would be curious to calculate how much faster light travels than a cannon ball.

Tutor. Suppose a cannon ball to travel at the rate of twelve miles a minute: light is calculated to move a

million of times faster than that; yet Dr. Akenside conjectures, that there may be stars so distant from us that the light proceeding from them has not yet reached the earth:—

——— Whose unfading light
Has travell'd the profound six thousand years,
Nor yet arriv'd in sight of mortal things.

Charles. Is it to this author that Dr. Young alludes in these lines?

How distant some of the nocturnal suns!
So distant, says the sage, 'twere not absurd
To doubt, if beams set out at Nature's birth,
Are yet arriv'd at this so foreign world;
Though nothing half so rapid as their flight.

Tutor. He probably referred to Huygens, an eminent astronomer, who threw out the idea before Akenside was born.

James. And you say the particles of light move in all directions.

Tutor. Here is a sheet of thick brown paper, and I make only a small pin-hole in it, and then, through that hole, I can see the same objects, such as the sky, trees, houses, &c. as I could if the paper were not there.

Charles. Do we only see objects by means of the rays of light which flow from them?

Tutor. In no other way: and therefore the light that comes from the landscape, which I view by looking through the small hole in the paper, must come in all directions at the same time.—Take another instance: if a candle be placed on an eminence in a dark night, it may be seen all round for the space of half a mile; in other words, there is no

place within a sphere of a mile diameter, where the candle cannot be seen, that is, where some of the rays from the small flame will not be found.

James. Why do you limit the distance to half a mile?

Tutor. The distance, of course, will be greater or less, according to the size of the candle; but the degree of light, like heat, diminishes in proportion as you go farther from the luminous body.

Charles. Does it follow the same law as *gravity**.

Tutor. It does; the *intensity* or degree of light decreases as the square of the distance from the luminous body increases.

James. Do you mean that, at the

* See Vol. I, Conversation VII.

distance of two yards from a candle, we shall have four times less light than we should have if we were only one yard from it?

Tutor. I do: and at three yards' distance nine times less light; and at four yards distance you will have sixteen times less light than you would were you within a yard of the object. I have one more thing to tell you: light always moves in straight lines.

James. How is that known?

Tutor. Look through a straight tube at any object, and the rays of light will flow readily from it to the eye; but let the tube be bent, and the object cannot be seen through it, which proves that light will move only in a straight line.

This is plain also from the shadows

which opaque bodies cast; for if the light did not describe straight lines, there would be no shadow. Hold any object in the light of the sun, or a candle, as a square board or book, and the shadow caused by it proves that light moves only in right or straight lines; for the space immediately behind the board or book is in shade.

Charles. It is not dark there.

Tutor. No: it is enlightened in a degree by rays reflected from the illuminated space.

CONVERSATION II.

Of Rays of Light.—Of Reflection and Refraction.

CHARLES. You talked, the last time we met, of the rays of light flowing or moving, what do you mean by a *ray of light?*

Tutor. Light, you know, is supposed to be made up of indefinitely small particles; now one or more of these particles, in motion from any body, is called a ray of light.—If the supposition be true, that light consists of particles flowing from a

luminous body, as the sun, and that these particles are about eight minutes in coming from the sun to us; then, if the sun were blotted from the heavens, we should actually have the same appearance for eight minutes after the destruction of that body as we now have.

James. I do not understand how we could see a thing that would not exist.

Tutor. The sun is perpetually throwing off particles of light, which travel at the rate of twelve millions of miles in a minute, and it is by these that the image of the body is impressed on our eye. The sun being blotted from the firmament would not affect the course of the particles that had the instant before

been thrown from his body, they would travel on as if nothing had happened, and, till the last particles had reached the eye, we should think we saw the sun as much as we do now.

Charles. Do we not actually see the body itself?

Tutor. The sense of sight may, perhaps, not be unaptly compared to that of smell: a grain of musk will throw off its odoriferous particles all round, to a considerable distance; now, if you or I happen to be near it, the particles, which fall upon certain nerves in the nose, will excite in us those sensations by which we say we have the smell of musk. In the same way particles of light are flowing in every direction from the grain of musk, some of which fall on the

eye, and these excite different sensations, from which we say we see a piece of musk.

Charles. But the musk will, in time, be completely dissipated, by the act of throwing off the fine particles; whereas a chair or table may throw off its rays so as to be visible, without ever diminishing its size.

Tutor. True: because whatever is distinguished by the sense of smell, is known only by the particles of the odoriferous body itself flowing from it: whereas a body distinguished by the sense of sight is known by the rays of light, which first fall on the body, and are then *reflected* from it.

James. What do you mean by being *reflected?*

Tutor. If I throw this marble

smartly against the wainscot, will it remain where it was thrown?

James. No: it will *rebound* or come back again.

Tutor. What you call rebounding, writers on optics denominate *reflection.* When a body of any kind, whether it be a marble with which you play, or a particle of light, strikes against a surface, and is sent back again, it is said to be reflected. If you shoot a marble straight against a board, or other obstacle, it comes back in the same line, or nearly so; but suppose you throw it sideways, does it return to the hand?

Charles. Let me see: I will shoot this marble against the *middle* of one side of the room from the corner of the opposite side.

James. You see, instead of coming back to your hand, it goes off to the other corner directly opposite to the place from which you sent it.

Tutor. This will lead us to the explanation of one of the principal definitions in optics, viz. *that the angle of reflection is always equal to the angle of incidence.* You know what an angle is? *

Charles. We do: but not what an angle of *incidence* is.

Tutor. I said a ray of light was a particle of light in motion: now there are *incident* rays, and *reflected* rays.

The *incident* rays are those which *fall on* the surface; and the *reflected* rays are those which are *sent off* from it.

* See Vol. I, Conversation I.

Charles. Does the line made or supposed to be made by the marble in *going to* the wainscot represent the *incident* ray, and in *going from* it does it represent the *reflected* ray?

Tutor. It does: and the wainscot may be called the reflecting surface.

James. Then what are the angles of incidence and reflection?

Tutor. Suppose you draw the lines on which the marble travelled, both to the wainscot, and from it again.

Charles. I will do it with a piece of chalk, as nearly as I can.

Tutor. Now draw a perpendicular* from the point where the marble

* If the point be exactly in the middle of one side of the room, a perpendicular is readily drawn by finding the middle of the opposite side, and joining the two points.

struck the surface, that is, where your two lines meet.

Charles. I see there are two angles, and they seem to be equal.

Tutor. We cannot expect mathematical precision in such trials as these; but, if the experiment were accurately made, the two angles would be perfectly equal: the angle contained between the incident ray and the perpendicular is called the angle of incidence; and that contained between the perpendicular and reflected ray is called the angle of reflection.

James. Are these, in all cases, equal, shoot the marble as you will?

Tutor. They are: and the truth holds equally with the rays of light:—both of you stand in front of the looking-glass. You see yourselves, and

one another also; for the rays of light flow from you to the glass, and are reflected back again in the same lines. Now both of you stand on one side of the room. What do you see?

Charles. Not ourselves, but the furniture on the opposite side.

Tutor. The reason of this is, that the rays of light, flowing from you to the glass, are reflected to the other side of the room.

Charles. Then, if I go to that part, I shall see the rays of light flowing from my brother:—and I do see him in the glass.

James. And I see Charles.

Tutor. Now the rays of light flow from each of you to the glass, and are reflected to one another: but neither of you sees himself.

Charles. No: I will move in front of the glass; now I see myself, but not my brother; and, I think, I understand the subject very well.

Tutor. Then explain it to me by a figure, which you may draw on the slate.

Charles. Let A B (Plate I, Fig. 1) represent the looking-glass: if I stand at C, the rays flow from me to the glass, and are reflected back in the same line, because now there is no angle of incidence, and of course no angle of reflection; but, if I stand at x, then the rays flow from me to the glass, but they make the angle x O C, and therefore they must be reflected in the line O y, so as to make the angle y O C, which is the angle of reflection, equal to the angle x O C. And, if James stand at y, he will see

me at x, and I, standing at x, shall see him at y.

Tutor. The same thing occurs with respect to every plain reflecting surface, as well as in a looking-glass; as in clear water, or in highly polished steel, mahogany, &c.

CONVERSATION III.

Of the Refraction of Light.

CHARLES. If glass stop the rays of light, and reflect them, why cannot I see myself in the window?

Tutor. It is the silvering on the glass which causes the reflection, otherwise the rays would pass through it without being stopped, and if they were not stopped, they could not be reflected. No glass, however, is so transparent, but it reflects some rays: put your hand to within three or four

inches of the window, and you see clearly the image of it.

James. So I do, and the nearer the hand is to the glass, the more evident is the image, but it is formed on the other side of the glass, and beyond it too.

Tutor. It is; this happens also in looking-glasses: you do not see yourself on the surface, but apparently as far behind the glass, as you stand from it in the front.

Whatever suffers the rays of light to pass through it, is called a *medium*. Glass, which is transparent, is a medium; so also is air, water, and indeed all fluids that are transparent are called *media*, and the more transparent the body, the more perfect is the medium.

Charles. Do the rays of light pass through these in a straight line?

Tutor. They do: but not in precisely the same direction in which they were moving before they entered it. They are *bent* out of their former course, and this is called *refraction.*

James. Can you explain this term more clearly?

Tutor. Suppose A B (Plate I, Fig. 2) to be a piece of glass, two or three inches thick; and a ray of light, S *a*, to fall upon it at *a*, it will not pass through in the direction S *s*, but when it comes to *a*, it will be bent towards the perpendicular *a b*, and go through the glass in the course *a x*, and when it comes into the air, it will pass on in the direction *x z*, which is paralel to S *s*.

Charles. Does this happen if the ray fall perpendicularly on the glass at P *a*?

Tutor. In that case there is no refraction, but the ray proceeds in its passage through the glass, precisely in the same direction as it did before it entered it, namely, in the direction P *b*.

James. Refraction, then, takes place only when the rays fall obliquely or slantways on the medium?

Tutor. Just so: rays of light may pass out of a rarer into a denser medium, as from air into water or glass: or they may pass from a denser medium into a rarer, as from water into air.

Charles. Are the effects the same in both cases?

Tutor. They are not; and I wish

you to remember the difference. When light passes out of a rarer into a denser medium, it is drawn *to* the perpendicular: thus, if S *a* pass from air into glass, it moves, in its passage through it, in the line *a x*, which is nearer to the perpendicular P *b* than the line *a* S, which was its first direction.

But when a ray passes from a denser medium into a rarer, it moves in a direction *farther from* the perpendicular; thus if the ray *x a* pass through glass or water into air, it will not, when it comes to *a*, move in the direction *a m*, but in the line *a* S, which is farther than *a m* from the perpendicular *a* P.

James. Can you show us any experiment in proof of this?

Tutor. Yes, I can; here is a com-

mon earthen pan, on the bottom of which I will lay a shilling, and will fasten it with a piece of soft wax, so that it shall not move from its place, while I pour in some water. Stand back, till you just lose sight of the shilling.

James. The side of the pan now completely hides the sight of the money from me.

Tutor. I will pour in a pitcher of clear water.

James. I now see the shilling; how is this to be explained?

Tutor. Look to the last figure, and conceive your eye to be at s, *a b* the side of the pan, and the piece of money to be at *x*: now, when the pan is empty, the rays of light flow from *x*, in the direction *x a m*; but your eye is at s, of course

you cannot see any thing by the ray proceeding along *x a m*. As soon as I put the water into the vessel, the rays of light proceed from *x* to *a*, but there they enter from a denser to a rarer medium; and, therefore, instead of moving in *a m*, as they did when there was no water, they will be bent *from* the perpendicular, and will come to your eye at s, as if the shilling were situate at *n*.

James. And it does appear to me to be at *n*.

Tutor. Remember what I am going to tell you, for it is a sort of axiom in optics: "We see every thing in the *direction* of that line in which the rays approach us last." Which may be thus illustrated: I place a candle before the looking-glass, and, if you stand also before the

glass, the image of the candle appears behind it; but if another looking-glass be so placed as to receive the reflected rays of the candle, and you stand before this second glass, the candle will appear behind that; because the mind transfers every object seen along the line in which the rays came to the eye last.

Charles. If the shilling were not moved by the pouring in of the water, I do not understand how we could see it afterwards.

Tutor. But you do see it now at the point *n*, or rather at the little dot just above it, which is an inch or two from the place where it was fastened at the bottom, and from which, you may convince yourself, it has not moved.

James. I should like to be con-

vinced of this: will you make the experiment again, that I may be satisfied of it.

Tutor. You may make it as often as you please, and the effect will always be the same; but you must not imagine that the shilling only will appear to move, the bottom of the vessel seems also to change its place.

James. It appears to me to be raised higher as the water is poured in.

Tutor. I trust you are satisfied by this experiment; but I can show you another equally convincing; but for this we stand in need of the sun.

Take an empty vessel A, a common pan or bason will answer the purpose (Plate I, Fig. 3), into a dark room, having only a very small hole in the window shutter: so place the bason that a ray of light s *s* shall fall upon

the bottom of it at *a*, here I make a small mark, and then fill the bason with water. Now where does the ray fall?

James. Much nearer to the side at *b*.

Tutor. I did not move the bason, and therefore could have had no power in altering the course of the light.

Charles. It is very clear that the ray was refracted by the water at *s*, and I see that the effect of refraction, in this instance, has been to draw the ray nearer to a perpendicular, which may be conceived to be the side of the vessel.

Tutor. The same thing may be shown with a candle in a room otherwise dark: let it stand in such a manner as that the shadow of the side of a pan or box may fall somewhere

at the bottom of it; mark the place, and pour in water, and the shadow will not then fall so far from the side. For in this case, the rays of light pass *out of air*, which is a rare medium, *into water*, which is a denser medium, and are accordingly drawn nearer to the perpendicular.

James. Do all media refract equally.

Tutor. No: they differ according to their densities: that is, the denser medium has the greater refracting power. When a ray of light passes from air into water the refraction is 4 : 3; but when it passes from air into glass it is as 3 : 2; that is, the measures of the ratios are $\frac{4}{3}$ and $\frac{3}{2}$: multiply both fractions by any number, as 12, and the latter will be seen to be the larger.

CONVERSATION IV.

Of the Reflection and Refraction of Light.

TUTOR. We will proceed to some farther illustrations of the laws of reflection and refraction. We shut out all the light except the ray that comes in at the small hole in the shutter: at the bottom of this bason, where the ray of light falls, I lay this piece of looking-glass; and if the water be rendered in a small degree opaque by mixing with it a few drops of

milk, and the room be filled with dust by sweeping a carpet, or any other means, then you will see the refraction which the ray from the shutter undergoes in passing into the water, the reflection of it at the surface of the looking-glass, and the refraction which takes place when the ray leaves the water and passes again into the air.

James. Does this refraction take place in all kinds of glass?

Tutor. It does: but when the glass is very thin, as in window glass, the deviation is so small, as to be generally overlooked. You may now understand why the oar in the water appears bent, though it be really straight; for, suppose A B (Plate I,

Fig. 4), represent water, and *m a x* the oar, the image of the part *a x* in the water will lie above the object, so that the oar will appear in the shape *m a n*, instead of *m a x*. On this account, also, a fish in the water appears nearer the surface than it actually is, and a marksman shooting at it must aim below the place which it seems to occupy.

Charles. Does the image of the object seen in the water always appear higher than the object really is?

Tutor. It appears one fourth nearer the surface than the object is. Hence a pond or river is a third part deeper than it appears to be, which is of importance to remember, for many a school-boy has lost his life by imagining the water into which

he plunged was within his depth, as boys say.

James. You say the bottom appears one *fourth* nearer the surface than it is; and then that the water is a third deeper than it seems to be: I do not understand this.

Tutor. Suppose the river to be six feet deep, which is sufficient to drown you or me, if we cannot swim; I say the bottom will appear to be only four feet and a half from the surface, in which case you could stand and have the greater part of your head above it; of course it appears to be a foot and a half shallower than it is; but a foot and a half is just the *third* part of four feet and a half.

Charles. Can this be shown by experiment?

Tutor. It may:—I take this large

empty pan, and with a piece of soft wax stick a piece of money at the bottom, but so that you can just see it as you stand; keep your position, and I will pour in a quantity of water gradually, and tell me the appearance.

Charles. The shilling rises exactly in the same proportion as you pour in the water.

Tutor. Recollect, then, in future, that we cannot judge of *distances* so well in water as in air.

James. And I am sure we cannot of magnitudes: for, in looking through the sides of a globular glass at some gold and silver fish, I thought them very large; but, if I looked down upon them from the top, they appeared very much smaller.

Tutor. Here the convex or round

shape of the glass becomes a magnifier, the reason of which will be explained hereafter. A fish will, however, look larger in water than it really is.—I will show you another experiment, which depends on refraction: here is a glass goblet two-thirds full of water; I throw into it a shilling, and place a plate on the top of it, and turn it quickly over, that the water may not escape. What do you see?

Charles. There seems certainly a half crown lying on the plate, and a shilling appears to be swimming above it in the water.

Tutor. So it seems indeed; but it is a deception, which arises from your seeing the piece of money in two directions at once, *viz.*, through the conical surface of the water at

the side of the glass, and through the flat surface at the top of the water. The conical surface, as was the case with the globular one in which the fish were swimming, magnifies the money; but by the flat surface the rays are only refracted, on which account the money is seen higher up in the glass, and of its natural size, or nearly so.

James. If I look sideways at the money, I only see the large piece; and, if only at top, I see it in its natural size and state.

Charles. Look again at the fish in the glass, and you will see through the round part two very large fish, and seeing them from the upper part, they appear of their natural size; the deception is the same as with the shilling in the goblet.

Tutor. The principle of refraction is productive of some very important effects. By this the sun, every clear morning, is seen several minutes before he comes to the horizon, and as long after he sinks beneath it in the evening.

Charles. Then the days are longer than they would be, if there was no such a thing as refraction. Will you explain how this happens?

Tutor. I will: you know we are surrounded with an atmosphere, which extends all round the earth, and above it to about the height of forty-five miles; now the dotted part of Fig. 5 represents that atmosphere: suppose a spectator stand at *s*, and the sun to be at *a*; if there were no refraction, the person at *s* would not see the rays of the sun till he were

situate with regard to the sun in a line $s\ x\ a$; because, when it was below the horizon, at b, the rays would pass by the earth in the direction $b\ x\ z$, but, owing to the atmosphere, and its refracting power, when the rays from b reach x, they are bent towards the perpendicular, and carried to the spectator at s.

James. Will he really see the image of the sun while it is below the horizon?

Tutor. He will; for it is easy to calculate the moment when the sun should rise and set, and, if that be compared with exact observation, it will be found, that the image of the sun is seen sooner or later than this by several minutes every clear day.

Charles. Are we subject to the

same kind of deception when the sun is actually above the horizon?

Tutor. We are always subject to it in these latitudes, for the sun is never in that place in the heavens where he appears to be.

James. Why in these latitudes particularly?

Tutor. Because with us the sun is never in the *zenith*, s, or directly over our heads; and, in that situation alone, his *true* place in the heavens is the same as his *apparent* place.

Charles. Is that because there is no refraction when the rays fall perpendicularly on the atmosphere?

Tutor. It is: but, when the sun (Plate I, Fig. 5) is at *m*, his rays will not proceed in a direct line *m o r*, but will be bent out of their course at *o*, and go in the direction *o s*, and

the spectator will imagine he sees the sun in the line *s o n*.

Charles. What makes the moon look so much larger, when it is just above the horizon, than when it is higher up?

Tutor. The thickness of the atmosphere when the moon is near the horizon, renders it less bright than when it is higher up, which leads us to suppose it is farther off in the former case than in the latter; and, because we imagine it to be farther from us, we take it to be a larger object than when it is higher up.

It is owing to the atmosphere that the heavens appear bright in the day-time. Without an atmosphere, only that part of the heavens would appear luminous in which the sun is seen; in that case, if we could live

without air, and should stand with our backs to the sun the whole heavens would appear as dark as night. We cannot, therefore, too highly estimate the importance of an atmosphere, that affords those reflections and refractions of light, which shed lustre over surrounding objects, and which form pleasing transitions from darkness to day, and from day to night, by means of twilight.

CONVERSATION V.

Definitions — Of the different kinds of Lenses—Of Mr. Parker's Burning Lens, and the effects produced by it.

TUTOR. I must claim your attention to a few other definitions; the knowledge of which will be wanted as we proceed.

A pencil of rays is any number that proceed from a point.

Parallel rays are such as move always at the same distance from each other.

Charles. That is something like

the definition of *parallel lines**. But, when you admitted the rays of light through the small hole in the shutter, they did not seem to flow from that point in parallel lines, but to recede from each other in proportion to their distance from that point.

Tutor. They did; and, when they do thus recede from each other, as in this figure (Plate I, Fig. 6), from c to *c d*, then they are said to *diverge*. But, if they continually approach towards each other, as in moving from *c d* to c, they are said to *converge*.

James. What does the dark part of this figure represent?

Tutor. It represents a glass lens, of which there are several kinds.

* Parallel lines are those which being infinitely extended never meet.

Charles. How do you describe a lens?

Tutor. A *lens* is a glass ground into such a form as to collect or disperse the rays of light which pass through it. Lenses are of different shapes, from which they take their names. They are represented here in one view (Plate I, Fig. 7): A is such a one as that in the last figure, and it is called a *plano-convex*, because one side is flat and the other convex; B is a *plano concave*, one side being *flat*, and the other is *concave*; C is a *double convex-lens*, because both sides are convex; D is a *double concave*, because both sides are concave; and E is called a *meniscus*, being convex on one side, and concave on the other: of this kind are all watch glasses.

James. I can easily conceive of diverging rays, or rays proceeding from a point; but what is to make them converge, or come to a point?

Tutor. Look again to the figure (Fig. 6); now *a*, *b*, *m*, &c., represent parallel rays, falling upon *c d*, a convex surface, of glass for instance, all of which, except the middle one, fall upon it obliquely, and, according to what we saw yesterday, will be refracted towards the perpendicular.

Charles. And I see they will all meet in a certain point in that middle line.

Tutor. That point c is called the *focus:* the dark part of this figure only represents the glass, as *c d n*.

Charles. Have you drawn the cir-

cle to show the exact curve of the different lenses?

Tutor. Yes: and you see that parallel rays falling upon a *plano-convex lens* (Fig. 6) meet at a point behind it, the distance of which, from the middle of the glass, is exactly equal to the diameter of the sphere of which the lens is a portion.

James. And in the case of a *double convex* is the distance of the focus of parallel rays equal only to the radius of the sphere? (Plate I, Fig. 8.)

Tutor. It is: and you see the reason of it immediately; for two concave surfaces have double the effect in refracting rays to what a single one has: the *latter* bringing them to a focus at the distance of the diameter, the former

at half that distance, or of the radius.

Charles. Sometimes, perhaps, the two sides of the same lens may have different curves: what is to be done then?

Tutor. If you know the radius of both the curves, the following rule will give you the answer:—

"As the sum of the radii of both curves or convexities is to the radius of either, so is double the radius of the other to the distance of the focus from the middle point."

James. Then, if one radius be four inches, and the other three inches, I say as $4 \times 3 : 4 :: 6 : \frac{24}{7} = 3\frac{3}{7}$, or to nearly three inches and a half. I saw a gentleman lighting his pipe yesterday by means of the sun's rays

and a glass: was that a double convex lens?

Tutor. I dare say it was: and you now see the reason of that which then you could not comprehend: all the rays of the sun that fall on the surface of the glass (see Fig. 8) are collected in the point *f*, which, in this case, may represent the tobacco in the pipe.

Charles. How do you calculate the heat which is collected in the focus?

Tutor. The force of the heat collected in the focus is in proportion to the common heat of the sun, as the area of the glass is to the area of the focus: of course, it may be a hundred or even a thousand times greater in the one case than in the other.

James. Have I not heard you say that Mr. Parker, of Fleet Street, made once a very large lens, which he used as a burning-glass?

Tutor. He formed one three feet in diameter, and, when fixed in its frame, it exposes a clear surface of more than two feet eight inches in diameter, and its focus, by means of another lens, was reduced to a diameter of half an inch. The heat produced by this was so great, that iron plates were melted in a few seconds: tiles and slates became red-hot in a moment, and were vitrified, or changed into glass: sulphur, pitch, and other resinous bodies, were melted under water: wood-ashes, and those of other vegetable substances, were turned in a moment into transparent glass.

Charles. Would the heat produced by it melt all the metals?

Tutor. It would: even gold was rendered fluid in a few seconds; notwithstanding, however, this intense heat at the focus, the finger might, without the smallest injury, be placed in the cone of rays within an inch of the focus.

James. There was, however, I should suppose, some risk in this experiment, for fear of bringing the finger too near the focus.

Tutor. Mr. Parker's curiosity led him to try what the sensation would be at the focus; and he describes it like that produced by a sharp lancet, and not at all similar to the pain produced by the heat of fire or a candle. Substances of a white colour were difficult to be acted upon.

Charles. I suppose he could make water boil in a very short time with the lens.

Tutor. If the water be very pure, and contained in a clear glass decanter, it will not be warmed by the most powerful lens. But a piece of wood may be burned to a coal, when it is contained in a decanter of water.

James. Will not the heat break the glass?

Tutor. It will scarcely warm it: if, however, a piece of metal be put in the water, and the point of rays be thrown on that, it will communicate heat to the water, and sometimes make it boil. The same effect will be produced if there be some ink thrown into the water.

If a cavity be made in a piece of charcoal, and the substance to be

acted on be put in it, the effect produced by the lens will be much increased. Any metal thus enclosed melts in a moment, the fire sparkling like that of a forge to which the blast of a bellows is applied.

Charles. Cannot the same effects be produced by a concave mirror?

Tutor. Every concave mirror, or speculum, whether made of glass or metal, collects the rays, dispersed through the whole concavity, after reflection, into a point or focus, and is therefore a burning mirror.

CONVERSATION VI.

Of Parallel Rays—Of diverging and converging Rays — Of the Focus and focal Distances.

CHARLES. I have been looking at the figures 6 and 8, and see that the rays falling upon the lenses are parallel to one another: are the sun's rays parallel?

Tutor. They are considered so: but you must not suppose that all the rays that come from the surface of an object, as the sun, or any other

body, to the eye, are parallel to each other, but it must be understood of those rays only which proceed from a single point. Suppose S (Plate I, Fig. 9) to be the sun, the rays which proceed from a single point A, do in reality form a cone, the *base* of which is the pupil of the eye, and its height is the distance from us to the sun.

James. But the breadth of the eye is nothing when compared to a line ninety-five millions of miles long.

Tutor. And for that reason, the various rays that proceed from a single point in the sun are considerd as parallel, because their inclination to each other is insensible. The same may be said of any other point, as C. Now all the rays, that we can admit by means of a small aperture,

or hole, must proceed from an indefinitely small point of the sun, and therefore they are justly considered as parallel.

If now we take a ray from the point A, and another from C, on opposite points of the sun's disk, they will form a sensible angle at the eye; and it is from this angle AEC that we judge of the apparent size of the sun, which is about half a degree in diameter.

Charles. Will the size of the pupil of the eye make any difference with regard to the appearance of the object?

Tutor. The larger the pupil, the brighter will the object appear, because the larger the pupil is, the greater number of rays it will receive from any single point of the object.—

And I wish you to remember what I have told you before, that whenever the appearance of a given object is rendered larger and brighter, we always imagine that the object is nearer to us than it really is, or than it appears at other times.

James. If there be nothing to receive the rays (Fig. 8) at *f*, would they cross one another and diverge?

Tutor. Certainly, in the same manner as they converge in coming to it; and, if another glass, F G, of the same convexity as D E, be placed in the rays at the same distance from the focus, it will so refract them, that, after going out of it, they will be parallel, and so proceed on in the same manner as they came to the first glass.

Charles. There is, however, this difference; all the rays, except the middle one, have changed sides.

Tutor. You are right, the ray B, which entered at bottom, goes out at the top *b*; and A, which entered at the top, goes out at the bottom *c*, and so of the rest.

If a candle be placed at *f*, the focus of the convex glass, the diverging rays in the space F *f* G, will be so refracted by the glass, that, after going out of it, they will become parallel again.

James. What will be the effect if the candle be nearer to the glass than the point *f*?

Tutor. In that case, as if the candle be at *g* (Plate II, Fig. 10), the rays will diverge after they have passed through the glass, and the

divergency will be greater or less in proportion as the candle is more or less distant from the focus.

Charles. If the candle be placed farther from the lens than the focus *f*, will the rays meet in a point after they have passed through it?

Tutor. They will: thus, if the candle be placed at *g* (Plate II, Fig. 11), the rays, after passing the lens, will meet at *x*; and this point *x* will be *more* or less distant from the glass, as the candle is *nearer* to, or farther from its focus. Where the rays meet, they form an *inverted* image of the flame of the candle.

James. Why so?

Tutor. Because that is the point where the rays, if they are not stopped, cross each other: to satisfy you on this head, I will hold in that point

a sheet of paper, and you now see that the flame of the candle is inverted.

James. How is this explained?

Tutor. Let A B C (Plate II, Fig. 12) represent an arrow placed beyond the focus F, of a double convex lens *d e f*, some rays will flow from every part of the arrow, and fall on the lens; but we shall consider only those which flow from the points A, B, and C. The rays which come from A, as A *d*, A *e*, and A *f*, will be refracted by the lens, and meet in A. Those which come from B, as B *d*, B *e*, and B *f*, will unite in *b*, and those, which come from C, will unite in C.

Charles. I see clearly how the rays from B are refracted, and unite in *b*; but it is not so evident with

regard to those from the extremities A and C.

Tutor. I admit it; but you must remember the difficulty consists in this, the rays fall more obliquely on the glass from those points than from the middle, and therefore the refraction is very different. The ray B F in the centre suffers no refraction, B *d* is refracted into *b*, and if another ray went from N, as N *d*, it would be refracted to *n*, somewhere between *b* and *a*, and the rays from A must, for the same reason, be refracted to *a*.

James. If the object A B C is brought nearer to the glass, will the picture be removed to a greater distance?

Tutor. It will: for then the rays will fall more diverging upon th glass, and cannot be so soon 61-

lected into the corresponding points behind it.

Charles. From what you have said, I see that if the object A B C be placed in F, the rays, after refraction, will go out parallel to one another; and if brought nearer to the glass than F, then they will diverge from one another, so that in neither case an image will be formed behind the lens.

James. To get an image, must the object be beyond the focus F?

Tutor. It must: and the picture will be bigger or less than the object, as its distance from the glass is greater or less than the distance of the object: if ABC (Fig. 12) be the object, cbA will be the picture; and if cbA be the object, A B C will be the picture.

Charles. Is there any rule to find the distance of the picture from the glass?

Tutor. If you know the focal distance of the glass and the distance of the object from the glass, the rule is this;

"Multiply the distance of the focus by the distance of the object, and divide the product by their difference, the quotient is the distance of the picture."

James. If the focal distance of the glass be seven inches, and the object be nine inches from the lens, I say, $\frac{7 \times 9}{2} = \frac{63}{2} = 31\frac{1}{2}$ inches; of course the picture will be very much larger than the object. For, as you have said, the picture is as much bigger or less than the object, as its

distance from the glass is greater or less than the distance of the object.

Tutor. If the focus be seven inches, and the object at the distance of seventeen inches, then the distance of the picture will be found thus $\frac{7 \times 17}{10} = \frac{119}{10} = 12$ inches nearly.

CONVERSATION VII.

Images of Objects inverted—Of the Scioptric Ball—Of Lenses and their Foci.

JAMES. Will the image of a candle, when received through a convex lens, be inverted?

Tutor. It will, as you shall see. Here is no light in this room but from the candle, the rays of which pass through a convex lens, and, by holding a sheet of paper in

a proper place, you will see a complete inverted image of the candle on it.

An object seen through a very small aperture appears also inverted, but it is very imperfect compared to an image formed with a lens; it is *faint* for want of light, and it is *confused* because the rays interfere with one another.

Charles. What is the reason of its being inverted?

Tutor. Because the rays from the extreme parts of the object must cross at the hole. If you look through a very small hole at any object, the object appears magnified. Make a pin-hole, in a sheet of brown paper, and look through it at the small print of this book.

James. It is, indeed, very much magnified.

Tutor. As an object approaches a convex lens, its image departs from it; and as the object recedes, its image advances. Make the experiment with a candle and a lens, properly mounted, in a long room: when you stand at one end of the room, and throw the image on the opposite wall, the image is large, but, as you come nearer to the wall, the image is small, and the distance between the candle and glass is very much increased.

I will now show you an instrument, called a *Scioptric Ball,* which is fastened into a window shutter of a room from which all light is excluded

except what comes in through this glass.

Charles. Of what does this instrument consist?

Tutor. Of a frame A B (Plate II, Fig. 13) and a ball of wood C, in which is a glass lens; and the ball moves easily in the frame in all directions, so that the view of any surrounding objects may be received through it.

James. Do you screw this frame into the shutter.

Tutor. Yes, a hole is cut in it for that purpose; and there are little brass screws belonging to it, such as those marked *s*. When it is fixed in its place, a screen must be set at a proper distance from the lens to receive on it images of the objects out

of doors. This instrument is sometimes called an artificial eye.

Charles. In what respects is it like the eye?

Tutor. The frame has been compared to the socket in which the eye moves, and the wooden ball to the whole globe of the eye; the hole in the ball represents the pupil, the convex lens corresponds to the crystalline humour*, and the screen to the retina.

James. The ball, by turning in all directions, is very like the eye, for without moving the head I can look on all sides, and upwards and downwards.

Tutor. Well, we will now place the screen properly, and turn the ball

* These terms will be explained in Conversation XV.

to the garden:—Here you see all the objects perfectly expressed.

James. But they are all inverted.

Tutor. That is the great defect belonging to this instrument; but I will tell you how it may be remedied: take a looking-glass, and hold it before you with its face towards the picture on the screen, and inclining a little downwards, and the images will appear erect in the glass, and even brighter than they were on the screen.

Charles. You have shown us in what manner the rays of light are refracted by convex lenses, when those rays are parallel: will there not be a difference if the rays *converge* or *diverge* before they enter the lens?

Tutor. Certainly: if rays *converge*

before they enter a convex lens, they will be collected at a point *nearer* to the lens than the focus of parallel rays. But if they *diverge* before they enter the lens, they will then be collected in a point *beyond* the focus of parallel rays.

There are concave lenses as well as convex, and the refraction which takes place by means of these differs from that which I have already explained.

Charles. What will the effect of refraction be, when parallel rays fall upon a double concave lens?

Tutor. Suppose the parallel rays, *a*, *b*, *c*, *d*, &c. (Plate II, Fig. 14), pass through the lens A B, they will *diverge* after they have passed through the glass.

James. Is there any rule for

ascertaining the degree of divergency?

Tutor. Yes, it will be precisely so much as if the rays had come from a radiant point X, which is the centre of the concavity of the glass.

Charles. Is that point called the focus?

Tutor. It is called the *virtual*, or *imaginary focus*. Thus, the ray *a*, after passing through the glass A B, will go in the direction *g h*, as if it had come from the point X, and no glass been in the way; the ray *b* would go on in the direction *m n*, and the ray *e* in the direction *r s*, and so on. The ray C X in the centre suffers no refraction, but proceeds precisely as if no glass had been in the way.

James. Suppose the lens had been

concave only on one side, and the other side had been flat, how would the rays have diverged?

Tutor. They would have diverged, after passing through it, as if they had come from a radiant point at the distance of a whole diameter of the convexity of the lens.

Charles. There is then a great similarity in the refraction of the convex and concave lens.

Tutor. True: the *focus* of a double convex is at the distance of the radius of convexity, and so is the *imaginary focus* of the double concave: and the *focus* of the plano-convex is at the distance of the diameter of the convexity, and so is the *imaginary focus* of the plano-concave.

You will find that images formed by a concave lens, or those formed

by a convex lens, where the object is *within* its principal focus, are in the same position with the objects they represent: they are also *imaginary*, for the refracted rays never meet at the foci whence they seem to diverge.

But the images of objects placed beyond the focus of a convex lens are inverted, and *real*, for the refracted rays do meet at their proper foci.

Do not forget, that the effect of convex lenses is to render the rays, that pass through them, convergent, and to bring them together into a focus. The effect of concave lenses is to render the rays, transmitted through them, more divergent.

CONVERSATION VIII.

Of the Nature and Advantages of Light—Of the Separation of the Rays of Light by Means of a Prism—And of compounded Rays, &c.

TUTOR. We cannot contemplate the nature of light without being struck with the great advantages which we enjoy from it. Without that blessing, our condition would be truly deplorable.

Charles. I well remember how feelingly Milton describes his situation after he lost his sight:—

——————With the year
Seasons return; but not to me returns
Day, or the sweet approach of ev'n or morn,
Or sight of vernal bloom, or summer's rose,
Or flocks, or herds, or human face divine;
But cloud instead, and ever-during dark
Surrounds me, from the cheerful ways of men
Cut off, and for the book of knowledge fair
Presented with an universal blank
Of Nature's works, to me expung'd and raz'd,
And wisdom, at one entrance, quite shut out.

Tutor. Yet his situation was rendered comfortable by means of friends and relations, who all possessed the advantages of light. But, if our world were deprived of light, what pleasure, or even comfort, could we enjoy. "How," says a good writer, "could we provide ourselves with food, and the other necessaries of life? How could we transact the least business? How

could we correspond with each other, or be of the least reciprocal service, without light, and those admirable organs of the body, which the Omnipotent Creator has adapted to the perception of this inestimable benefit?"

James. But you have told us that the light would be of comparatively small advantage without an atmosphere.

Tutor. The atmosphere not only *refracts* the rays of the light, so that we enjoy longer days than we should without it, but occasions that twilight, which is so beneficial to our eyes; for without it the appearance and disappearance of the sun would have been instantaneous: and in every twenty-four hours we should have experienced a sudden transition

from the brightest sun-shine to the most profound darkness, and from thick darkness to a blaze of light.

Charles. I know how painful that would be, from having slept in a very dark room, and having suddenly opened the shutters when the sun was shining extremely bright.

Tutor. The atmosphere reflects also the light in every direction; and, if there were no atmosphere, the sun would benefit those only who looked towards it, and to those whose backs were turned to that luminary it would all be darkness. Ought we not therefore gratefully to acknowledge the wisdom and goodness of the Creator, who has adapted these things to the advantage of his creatures; and may we not with Thomson devoutly exclaim: —

How then shall I attempt to sing of Him,
Who, light himself, in uncreated light
Invested deep, dwells awfully retir'd
From mortal eye, or angel's purer ken;
Whose single smile has, from the first of time,
Fill'd, overflowing, all yon lamps of heav'n,
That beam for ever through the boundless sky:
But, should He hide his face, th' astonish'd sun,
And all th'extinguish'd stars would, loos'ning, reel
Wide from their spheres, and Chaos come again.

James. I saw, in some of your experiments, that the rays of light, after passing through the glass, were tinged with different colours, what is the reason of this?

Tutor. Formerly, light was supposed to be a simple and uncompounded body; Sir Isaac Newton, however, discovered that it was not a simple substance, but was com-

posed of several parts, each of which has, in fact, a different degree of refrangibility.

Charles. How is that shown?

Tutor. Let the room be darkened, and let there only be a very small hole in the shutter to admit the sun's rays: instead of a lens I take a triangular piece of glass, called a *prism;* now, as in this there is nothing to bring the rays to a focus, they will, in passing through it, suffer different degrees of refraction, and be separated into the different coloured rays, which, being received on a sheet of white paper, will exhibit the seven following colours, *red, orange, yellow, green, blue, indigo,* and *violet:* and now you shall hear a poet's description of them.

——————— First the flaming *red*
Sprung vivid forth; the tawny *orange* next;
And next delicious *yellow;* by whose side
Fell the kind beams of all-refreshing *green.*
Then the pure *blue,* that swells autumnal skies,
Ethereal play'd; and then, of sadder hue,
Emerg'd the deepen'd *indigo,* as when
The heavy-skirted evening droops with frost,
While the last gleamings of refracted light
Dy'd in the fainting *violet* away.

THOMSON.

James. Here are all the colours of the rainbow: the image on the paper is a sort of oblong.

Tutor. That oblong image is usually called a *spectrum;* and, if it be divided into 360 equal parts, the red will occupy 45 of them, the orange 27, the yellow 48, the green and the blue 60 each, the indigo 40, and the violet 80.

Charles. The shade of difference

in some of these colours seems very small indeed.

Tutor. You are not the only person who has made this observation; some experimental philosophers say there are but three original and truly distinct colours, *viz.*, the *red*, *yellow*, and *blue*.

Charles. What is called the *orange* is surely only a mixture of the red and yellow, between which it is situated.

Tutor. In like manner the *green* is said to be a mixture of the yellow and blue, and the *violet* is but a fainter tinge of the indigo.

James. How is it then that light, which consists of different colours, is usually seen as white?

Tutor. By mixing the several colours in due proportion white may be produced.

James. Do you mean to say, that a mixture of red, orange, yellow, green, blue, indigo, and violet, in any proportion, will produce a white?

Tutor. If you divide a circular surface into 360 parts, and then paint it in the proportion just mentioned, that is, 45 of the parts red, 27 orange, 48 yellow, &c., and turn it round with great velocity, the whole will appear of a dirty white; and, if the colours were more perfect, the white would be so too.

James. Was it then owing to the separation of the different rays, that I saw the rainbow colours about the edges of the image made with the lens?

Tutor. It was: some of the rays were scattered, and not brought to a focus, and these were divided in the

course of refraction. And I may tell you now, though I shall not explain it at present, that the rainbow in the heavens is caused by the separation of the rays of light into their component parts.

Charles. And was that the cause of the colours which we saw on some soap bubbles which James was making with a tobacco-pipe?

Tutor. It was. These bubbles are nothing more tnan thin bladders of the solution, whose thickness is continually varying; which is the cause of the variety of colours which they exhibit.

CONVERSATION IX.

Of Colours.

CHARLES. After what you said yesterday, I am at a loss to know the cause of different colours: the cloth on this table is green; that of which my coat is made is blue: what makes the difference in these? Am I to believe the poet, that

——Colours are but phantoms of the day,
With that they're born, with that they fade away;
Like beauty's charms, they but amuse the sight,
Dark in themselves, till by reflection bright;

With the sun's aid, to rival him they boast;
But, light withdrawn, in their own shades are
lost. HUGHES.

Tutor. All colours are supposed to exist only in the light of luminous bodies, such as the sun, a candle, &c., and that light falling incessantly upon different bodies is separated into its seven primitive colours, some of which are absorbed, while others are reflected.

James. Is it from the reflected rays that we judge of the colour of objects?

Tutor. It has generally been thought so; thus the cloth on the table absorbs all the rays but the green, which it reflects to the eye: but your coat is of a different texture, and absorbs all but the blue rays.

Charles. Why is paper and the snow white?

Tutor. The whiteness of paper is occasioned by its reflecting the greatest part of all the rays that fall upon it. And every flake of snow, being an assemblage of frozen globules of water sticking together, reflects and refracts the light that falls upon it in all directions, so as to mix it very intimately, and produce a white image on the eye.

James. Does the whiteness of the sun's light arise from a mixture of all the primary colours?

Tutor. It does, as may be easily proved by an experiment; for, if any of the seven colours be intercepted at the lens, the image in a great measure loses its whiteness. With the prism, I will divide the ray into its

seven colours * ; I will then take a convex lens, in order to re-unite them into a single ray, which will exhibit a round image of a shining white; but, if only five or six of these rays be taken with the lens, it will produce a dusky white.

Charles. And yet to this white colour of the sun we are indebted for all the fine colours exhibited in nature:—

Fairest of beings! first created light!
Prime cause of beauty! for from thee alone
The sparkling gem, the vegetable race,
The nobler worlds that live and breathe, their charms,
The lovely hues peculiar to each tribe,
From thy unfailing source of splendour draw.

MALLET.

* A figure will be given on this subject, with explanations, Conversation XVIII, on the Rainbow.

Tutor. These are very appropriate lines, for without light the diamond would lose all its beauty.

James. The diamond, I know, owes its brilliancy to the power of reflecting almost all the rays of light that fall on it; but are vegetable and animal tribes equally indebted to it?

Tutor. What does the gardener do to make his endive and lettuces white?

Charles. He ties them up.

Tutor. That is, he shuts out the light, and by this means they become blanched. I could produce you a thousand instances to show, not only that the colour, but even the existence of vegetables, depend upon light. Close wooded trees have only leaves on the outside, such is the cedar in the garden. Look up the

inside of a yew tree, and you will see that the inner branches are almost, or altogether barren of leaves. Geraniums and other green-house plants turn their flowers to the light; and plants in general, if doomed to darkness, soon sicken and die.

James. There are some flowers, the petals of which are, in different parts, of different colours: how do you account for this?

Tutor. The flower of the heartsease is of this kind; and, if examined with a good microscope, it will be found that the *texture* of the blue and yellow parts is very different. The texture of the leaves of the white and red rose is also different. Clouds, also, which are so various in their colours, are undoubtedly more or less dense, as well as being dif-

ferently placed with regard to the eye of the spectator; but they all depend on the light of the sun for their beauty, to which the poet refers:—

But see, the flush'd horizon flames intense
With vivid red, in rich profusion stream'd
O'er heaven's pure arch. At once the clouds assume
Their gayest liveries; *these* with silvery beams
Fring'd lovely; splendid *those* in liquid gold:
And speak their sov'reign's state. He comes, behold!
Fountain of light and colour, warmth, and life!
The king of glory!

MALLET.

Charles. Are we to understand, that all colours depend on the reflection of the several coloured rays of light?

Tutor. This seems to have been the opinion of Sir Isaac Newton: but

he concluded, from various experiments on this subject, that every substance in nature, provided it be reduced to a proper degree of thinness, is transparent. Many transparent media reflect one colour, and transmit another: gold-leaf reflects the yellow, but it transmits a sort of green colour by holding it up against a strong light.

Mr. Delaval, a gentleman who a few years since made many experiments to ascertain how colours are produced, undertakes to show that they are exhibited by transmitted light alone, and not by reflected light.

James. I do not see how that can be the case with bodies that are not transparent.

Tutor. He infers, from his ex-

periments, which you may hereafter examine for yourselves, that the original fibres of all substances, when cleared of heterogeneous matter, are perfectly white, and that the rays of light are reflected from these white particles, through the colouring matter with which they are covered, and that this colouring matter serves to intercept certain rays in their passage through it, while a free passage being left to others, they will exhibit, according to these circumstances, different colours.—The red colour of the shells of lobsters after boiling, he says, is only a superficial covering spread over the white calcareous earth, of which the shells are composed, and may be removed by scraping or filing. Before the application of heat it is so thick as to appear

black, being too thick to admit the passage of light to the shell and back again. The case is the same with feathers, which owe their colours to a thin layer of transparent matter on a white ground.

CONVERSATION X.

Reflected Light, and Plain Mirrors.

TUTOR. We now come to treat of a different species of glasses, *viz.* of *mirrors*, or, as they are sometimes called, specula.

James. A looking-glass is a mirror, is it not?

Tutor. Mirrors are made of glass, silvered on one side; they are also made of highly polished metal. There are three kinds of mirrors, the *plain*, the *convex*, and the *concave*.

Charles. You have shown us that,

in a looking-glass, or plain mirror, "The angle of reflection is always equal to the angle of incidence *."

Tutor. This rule is not only applicable to plain mirrors, but to those which are convex and concave also, as I shall show you to-morrow. But I wish to make some observations first on plain mirrors. In the first place, if you wish to see the complete image of yourself in a plain mirror, or looking-glass, it must be *half* as long as you are high.

James. I should have imagined the glass must have been as long as I am high.

Tutor. In looking at your image in the glass, does it not seem to be as far behind the glass as you stand before it?

* See page 18.

James. Yes: and, if I move forwards or backwards, the image behind the glass seems to approach or recede.

Tutor. Let *a b* (Plate II, Fig. 15) be the looking-glass, and A the spectator, standing opposite to it. The ray from his eye will be reflected in the same line A *a*, but the ray C *b* flowing from his foot, in order to be seen at the eye, must be reflected by the line *b* A.

Charles. So it will; for, if *x b* be a line perpendicular to the glass, the incident angle will be C *b x*, equal to the reflected angle A *b x*.

Tutor. And therefore the foot will appear behind the glass at D along the line A *b* D, because that is the line in which the ray last approaches the eye.

James. Is that part of the glass

a b intercepted by the lines A B and A D, equal exactly to half the length B D, or A C?

Tutor. It is: A *a b* and A B D may be supposed to form two triangles, the sides of which always bear a fixed proportion to one another; and, if A B is double of A *a*, as in this case it is, B D will be double of *a b*, or at least of that part of the glass intercepted by A B and A D.

Charles. This will hold true, I see, stand at what distance we please from the glass.

Tutor. If you walk towards a looking-glass, your image will approach, but with a double velocity, because the two motions are equal and contrary. But if, while you stand before a looking-glass, your brother walk up to you from behind,

his image will appear to you to move at the same rate as he walks, but to him the velocity of the image will appear to be double; for with regard to you, there will be but one motion, but with regard to him, there will be two equal and contrary ones.

James. If I look at the reflection of a candle in a looking-glass, I see in fact two images, one much fainter than the other: what is the reason of this?

Tutor. The same may be observed of any object that is strongly illuminated, and the reason of the double image is, that a part of the rays are immediately reflected from the upper surface of the glass, which form the faint image, while the greater part of them are reflected from the farther surface, or silvering part, and from

the vivid image. To see these two images you must stand a little sideways, and not directly before the glass.

Charles. What is meant by the expression of "An image being formed behind a reflector?"

Tutor. It is intended to denote that the reflected rays come to the eye with the same inclination as if the object itself were actually behind the reflector. If you, standing on one side of the room, see the image of your brother, who is on the other side, in the looking glass, the image seems to be formed behind the glass; that is, the rays come to your eye precisely in the same way as they would if your brother himself stood in that place without the intervention of a glass.

James. But the image in the glass is not so bright or vivid as the object.

Tutor. A plain mirror is in theory supposed to reflect all the light which falls upon it, but in practice nearly half the light is lost on account of the inaccuracy of the polish, &c.

Charles. Has it not been said, that Archimedes, at the siege of Syracuse, burned the ships of Marcellus, by a machine composed of mirrors?

Tutor. Yes: but we have no certain accounts that may be implicitly relied on. M. Buffon, about fifty or sixty years ago, burned a plank at the distance of seventy feet with forty plain mirrors.

James. I do not see how they can act as burning-glasses.

Tutor. A plain mirror reflects the light and heat coming from the sun, and will illuminate and heat any substance on which they are thrown, in the same manner as if the sun shone upon it. Two mirrors will reflect on it a double quantity of heat; and, if 40 or 100 mirrors could be so placed as to reflect from each the heat coming from the sun, on any particular substance, they would increase the heat 40 or 100 times.

CONVERSATION XI.

Of Concave Mirrors—their Uses—How they act.

JAMES. To what uses are concave mirrors applied?

Tutor. They are chiefly used in reflecting telescopes; that is, in telescopes adapted to viewing the heavenly bodies. And, as you like to look at Jupiter's little moons and Saturn's ring through my telescope, it may be worth your while to take some pains to know by what means this pleasure is afforded you.

Charles. I shall not object to any attention necessary to comprehend the principles on which these instruments are formed.

Tutor. A B (Plate II, Fig. 16) represents a concave mirror, and *a b*, c *d*, *e f*, three parallel rays of light falling upon it. C is the centre of concavity; that is, one leg of your compasses being placed on C, and then open them to the length C *d*, and the other leg will touch the mirror A B in all its parts.

James. Then all the lines drawn from C to the glass will be equal to one another, as C *b*, C *d*, and C *f*?

Tutor. They will: and there is another property belonging to them; they are all perpendicular to the glass in the parts where they touch.

Charles. That is, c *b* and c *f* are perpendicular to the glass at *b* and *f*, as well as c *d* at *d*.

Tutor. Yes, they are:—c *d* is an *incident* ray, but, as it passes through the centre of concavity, it will be reflected back in the same line; that is, as it makes no angle of incidence, so there will be no angle of reflection: *a b* is an *incident* ray, and I want to know what will be the direction of the reflected ray?

Charles. Since c *b* is perpendicular to the glass at *b*, the angle of incidence is *a b* c; and, as the angle of reflection is always equal to the angle of incidence, I must make another angle, as c *b m*, equal to *a b* c*,

* To make an angle c *b m*, equal to another given one, as *a b* c. From *b*, as a centre with

and then the line *b m* is that in which the incident ray will move after reflection.

Tutor. Can you, James, tell me how to find the line in which the incident ray *e f* will move after reflection?

James. Yes: I will make the angle c *f m* equal to c *f e*, and the line *f m* will be that in which the reflected ray will move; therefore *e f* is reflected to the same point *m* as *a b* was.

Tutor. If, instead of two incident rays, any number were drawn parallel to c *d*, they would every one be

any radius *b x*, describe the arc *x o*, which will cut c *b* in *z*:—take the distance *x z* in your compasses, and set off with it *z* o, and then draw the line *b* o m, and the angle m *b c* is equal to the angle *a b* c.

reflected to the same point *m*; and that point which is called the *focus of parallel rays* is distant from the mirror equal to half the radius c *d*.

James. Then we may easily find the point, without the trouble of drawing the angles, merely by dividing the radius of concavity into two equal parts.

Tutor. You may. The rays, as we have already observed, which proceed from any point of a celestial object, may be esteemed parallel at the earth, and therefore the image of that point will be formed at *m*.

Charles. Do you mean, that all the rays flowing from a point of a star, and falling upon such a mirror, will be reflected to the point *m*, where the image of the star will appear?

Tutor. I do, if there be any

thing at the point *m* to receive the image.

James. Will not the same rule hold with regard to terrestrial objects?

Tutor. No: for the rays, which proceed from any terrestrial object, however remote, cannot be esteemed strictly parallel, they therefore come *diverging;* and will not be converged to a *single point,* at the distance of half the radius of the mirror's concavity from the reflecting surface; but in *separate points,* at a little greater distance from the mirror than half the radius.

Charles. Can you explain this by a figure?

Tutor. I will endeavour to do so. Let A B (Plate II, Fig. 17) be a concave mirror, and M E any remote

object, from every part of which rays will proceed to every point of the mirror; that is, from the point M rays will flow to every point of the mirror, and so they will from E, and from every point between these extremities. Let us see where the rays, that proceed from M to A, *c*, and B, will be reflected, or, in other words, where the image of the point M will be formed.

James. Will all the rays that proceed from M to different parts of the glass be reflected to a single point?

Tutor. Yes, they will, and the difficulty is to find that point: I will take only three rays, to prevent confusion, *viz.* M A, M *c*, M B; and *c* is the centre of concavity of the glass.

Charles. Then, if I draw C A, that line will be perpendicular to the glass

at the point A: the angle M A C is now given, and it is the angle of incidence.

James. And you must make another equal to it as you did before.

Tutor. Very well: make C A x equal to M A C, and extend the line A x to any length you please.

Now you have an angle M c C made with the ray M c, and the perpendicular C c, which is another angle of incidence.

Charles. I will make the angle of reflection C c z equal to it, and the line c z being produced cuts the line A x in a particular point, which I will call m.

Tutor. Draw now the perpendicular C B, and you have, with it and the ray M B, the angle of incidence M B C: make another angle equal to it, as its angle of reflection,

James. There it is, C B *u*, and I find the line B *u* meets the other lines at the point *m*.

Tutor. Then *m* is the point in which all the reflected rays of M will converge; of course, the image of the extremity M of the arrow E M will be formed at *m*. Now the same might be shown of every other part of the object M E, the image of which will be represented by *e m*, which you see is at a greater distance from the glass than half C *c*, or radius.

Charles. The image is *inverted* also, and *less* than the object.

CONVERSATION XII.

Of Concave Mirrors, and Experiments on them.

TUTOR. If you understand what we conversed on yesterday, and what you have yourselves done, you will easily see how the image is formed by the large concave mirror of the reflecting telescope, when we come to examine the construction of that instrument. In a concave mirror, the image is *less* than the object, when the object is more remote from the

mirror than c, the centre of concavity; and, in that case, the image is between the object and mirror.

James. Suppose the object be placed in the *centre* c?

Tutor. Then the image and object will coincide: and, if the object is placed nearer to the glass than the centre c, then the image will be more remote, and bigger than the object.

Charles. I should like to see this illustrated by an experiment.

Tutor. Well, here is a large concave mirror: place yourself before it, beyond the centre of the concavity; and, with a little care in adjusting your position, you will see an inverted image of yourself in the air between you and the mirror, and of a less size than you are. When you see

the image, extend your hand gently, towards the glass, and the hand of the image will advance to meet it, till they both meet in the centre of the glass's concavity. If you carry your hand still farther, the hand of the image will pass by it, and come between it and the body: now move your hand to either side, and the image of it will move towards the other.

James. Is there any rule for finding the distance at which the image of an object is formed from the mirror?

Tutor. If you know the radius of the mirror's concavity, and also the distance of the object from the glass,

"Multiply the distance and radius together, and divide the product by

double the distance less by the radius, and the quotient is the distance required."

Tell me at what distance the image of an object will be, suppose the radius of the concavity of the mirror be 12 inches, and the object be at 18 inches from it.

James. I multiply 18 by 12, which is equal 216; this I divide by double 18, or 36, less by 12, that is 24; but 216 divided by 24 gives 9, which is the number of inches required.

Tutor. You may vary this example, in order to impress the rule on your memory; and I will show you another experiment. I take this bottle, partly full of water, and corked, and place it opposite the concave mirror, and beyond the focus, that it may appear to be reversed: now

stand a little farther distant than the bottle, and you will see the bottle inverted in the air, and the water, which is in the lower part of the bottle, will appear to be in the upper. I will invert the bottle, and uncork it, and, whilst the water is running out, the image will appear to be filling, but, when the bottle is empty, the illusion is at an end.

Charles. Concave mirrors are, I believe, sometimes used as burning-glasses.

Tutor. Since, as we have seen, it is the property of these mirrors to cause parallel rays to converge to a focus, and since the rays of the sun are considered as parallel, they are very useful as burning glasses, and the principal focus is the burning point.

James. Is the image formed by a concave mirror always before it?

Tutor. In all cases, except when the object is nearer to the mirror than the principal focus.

Charles. Is the image then behind the mirror?

Tutor. It is; and farther behind the mirror than the object is before it. Let A C (Plate III, Fig. 18) be a mirror, and *x* z the object between the centre K of the glass, and the glass itself; and the image *x y z* will be behind the glass, erect, curved, and magnified, and, of course, the image is farther behind the glass than the object is before it.

James. What would be the effect, if, instead of an opaque object *x* z, a luminous one, as a candle, were placed in the focus of a concave mirror?

Tutor. It would strongly illuminate a space of the same dimension as the mirror to a great distance; and if the candle were still nearer the mirror than the focus, its rays will enlighten a larger space. Hence you may understand the construction of many of the lamps which are now to be seen in many parts of London, and which are undoubtedly a great improvement in lighting the streets.

CONVERSATION XIII.

Of Concave and Convex Mirrors.

TUTOR. We shall devote another morning or two to the subject of reflection from mirrors of different kinds.

Charles. You have not said any thing about *convex* mirrors, and yet they are now very much in fashion in handsome drawing rooms: I have seen several, and always observed that the image was very much less than the object.

Tutor. A convex mirror is an ornamental piece of furniture, especially if it can be placed before a window, either with a good prospect, or where there are a number of persons passing and repassing in their different employments. The images reflected from these are smaller than the objects, erect, and behind the surface; therefore, a landscape or a busy scene delineated on one of them, is always a beautiful object to the eye. For the same reason, a glass of this kind, in a room in which large assemblies meet, forms an extremely interesting picture. You may easily conceive how the convex mirror diminishes objects, or the images of objects, by considering in what manner they are magnified by the concave mirror. If $x y z$ (Fig. 18) were

an object before a *convex* mirror A C, the image by reflection would be x z.

James. Would it not appear curved.

Tutor. Certainly: for, if the object be a right line, or a plain surface, its image must be curved, because the different points of the object are not equally distant from the reflector. In fact, the images formed by convex mirrors, if accurately compared with the objects, are never exactly of the same shape.

Charles. I do not quite comprehend in what manner reflection takes place at a convex mirror.

Tutor. I will endeavour, by a figure, to make it plain: C D (Plate III, Fig. 19) represents a convex mirror standing at the end of a room, before which the arrow A B is placed on one

side, or obliquely: where must the spectator stand to see the reflected image?

Charles. On the other side of the room.

Tutor. The eye E will represent that situation:—the rays from the external parts of the arrow, A and B, flow convergingly along A *a* and B *b*, and, if no glass were in the way, they would meet at P; but the glass reflects the ray A *a* along *a* E, and the ray B *b* along *b* E; and, as we always transfer the image of an object in that direction in which the rays approach the eye, we see the image of A along the line E *a* behind the glass, and the image of B along E *b*, and, of course, the image of the whole arrow is at S.

By means of a similar diagram, I

will show you more clearly the principle of the *concave* mirror. Suppose an object *e* (Plate III, Fig. 20) to be beyond the focus F, and the spectator to stand at Z, the rays *e b* and *e d* are reflected, and where they meet in E, the spectator will see the image.

James. That is between himself and the object.

Tutor. He must, however, be far enough from it to receive the rays after they have diverged from E, because every enlightened point of an object becomes visible only by means of a cone of diverging rays from it, and we cease to see it if the rays become parallel or converging.

Charles. Is the image inverted?

Tutor. Certainly, because the rays have crossed before they reach the eye.

You may see this subject in another point of view: let $x\,y$ (Plate III, Fig. 21) be a concave mirror, and O the centre of concavity: divide O A equally in F, and take the half, the third, and the fourth, &c. of F O, and mark these divisions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. Let A O be extended, and parts be taken in it equal to F O, at 2, 3, 4, &c. Now, if any of the points 1, 2, 3, 4, &c. be the focus of incident rays, the correspondent points 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. in O F will be the focus of the reflected rays, and *vice versa*.

James. Do you mean by that, if incident rays be at $\frac{1}{2}$, or $\frac{1}{3}$, or $\frac{1}{4}$, the reflected rays will be at 2, 3, 4?

Tutor. I do: place a candle at 2, and an inverted image will be seen at $\frac{1}{2}$: now place it at 4, and it will also move back to $\frac{1}{4}$: these images may

be taken on paper held in those respective places.

Charles. I see the farther you proceed one way with the candle, the nearer its inverted image comes to the point F.

Tutor. True: and it never gets beyond it, for that is the focus of parallel rays after reflection, or of rays that come from an infinite distance.

James. Suppose the candle were at O?

Tutor. Then the object and image will coincide: and, as the image of an object between F and a concave speculum is on the other side of the speculum, this experiment of the candle and paper cannot be made.

I will now just mention an experiment that we may hereafter make.

At one end of an oblong box, about two feet long, and fifteen inches wide, is to be placed a concave mirror; near the upper part of the opposite end a hole is made, and about the middle of the box is placed a hollow frame of pasteboard that confines the view of the mirror. The top of the box, next the end in which the hole is made, is covered with a glass, but the other half is darkened. Under the hole are placed, in succession, different pictures, properly painted, which are thrown into perspective by the mirror, and produce a beautiful appearance.

CONVERSATION XIV.

Of Convex Reflection — Of Optical Delusions — Of Anamorphoses.

CHARLES. You cannot, I see, make the same experiment, with the candle and a convex mirror, that you made yesterday with the concave one.

Tutor. Certainly, because the image is formed behind the glass; but it may, perhaps, be worth our while to consider how the effect is produced in a mirror of this

kind. Let *a b* (Plate III, Fig. 22) represent a convex mirror, and A*f* be half the radius of convexity, and take A F, F O, O B, &c. each equal A*f*. If incident rays flow from 2, the reflected rays will appear to come from behind the glass at $\frac{1}{2}$.

James. Do you mean, if a candle be placed at 2, the image of it will appear to be formed at $\frac{1}{2}$ behind the glass?

Tutor. I do: and if that, or any other object, be carried to 3, 4, &c. the image will also go backward to $\frac{1}{3}$, $\frac{1}{4}$, &c.

Charles. Then, as a person walks towards a convex spherical reflector, the image appears to walk towards him, constantly increasing in magni-

tude, till they touch each other at the surface.

Tutor. You will observe, that the image, however distant the object, is never farther off than at *f*; that is, the imaginary focus of parallel rays.

James. The difference then between convex and concave reflectors is, that the point *f* in the *former* is behind the glass, and in the *latter* it is before the glass, as F.

Tutor. Just so: from the property of diminishing objects, spherical reflectors are not only pleasing ornaments for our best rooms, but are much used by all lovers of picturesque scenery. "Small convex reflectors," says Dr. Gregory, "are made for the use of travellers, who, when fatigued by stretching the eye to Alps tower-

ing on Alps, can, by their mirror, bring these sublime objects into a narrow compass, and gratify the sight by pictures which the art of man in vain attemps to imitate*."

Concave mirrors have been used for many other and different purposes; for, by them, with a little ingenuity, a thousand illusions may be practised on the ignorant and incredulous.

Charles. I remember going with you to see an exhibition in Bond Street, which you said depended on a concave mirror: I was desired to look into a glass; I did so, and started back, for I thought the point of a dagger would have been in my face. I looked again, and a death's head

* See Economy of Nature, Vol. I. p. 26, second edition.

snapped at me; and then I saw a most beautiful nosegay, which I wished to grasp, but it vanished in an instant.

Tutor. I will explain how these deceptions are managed: let E F (Plate III, Fig. 23) be a concave mirror 10 or 12 inches in diameter, placed in one room; A B the wainscot that separates the spectator from it: but in this there is a square or circular opening which faces the mirror exactly. A nosegay, for instance, is inverted at C, which must be strongly illuminated by means of an Argand's lamp; but no direct light from the lamp is to fall on the mirror. Now a person standing at G will see an image of the nosegay at D.

James. What is to make it vanish?

Tutor. In exhibitions of this kind there is always a person behind the wainscot in league with the man that attends the spectator, who removes the real nosegay upon some hint understood between them.

Charles. Was it then upon the man behind the scene that the approaching sword, and the advancing death's head, &c. depended?

Tutor. It was: and persons have undertaken to exhibit the ghosts of the dead by contrivances of this kind: for if a drawing of the deceased be placed instead of the nosegay, it may be done. But such exhibitions are not to be recommended, and indeed ought never to be practised, without explaining the whole process to the astonished spectator afterwards.

If a large concave mirror be placed before a blazing fire, so as to reflect the image of the fire on the flap of a bright mahogany table, a spectator suddenly introduced into the room will suppose the fire to be on the table.

If two large concave mirrors, A and B (Plate III, Fig. 24), be placed opposite each other, at the distance of several feet, and red hot charcoal be put in the focus D, and some gunpowder in the other focus C, it will presently take fire. The use of a pair of bellows may be necessary to make the charcoal burn strongly.

This experiment may be varied by placing a thermometer in one focus, and lighted charcoal in the other, and it will be seen that the quicksilver in the thermometer will rise as the

fire increases, though another thermometer, at the same distance from the fire, but not in the focus of the glass, will not be affected by it.

James. I have seen concave glasses, in which my face has been rendered as long as my arm, or as broad as my body: how are these made?

Tutor. These images are called *anamorphoses*, and are produced from *cylindrical* concave mirrors: and, as the mirror is placed either *upright*, or on its *side*, the image of the picture is distorted into a very long or very broad image.

In the cloister of Minims, at Paris, there are two anamorphoses traced upon two of the sides of the cloister, one representing a Magdalen, and the other St. John writing his gospel. These, when viewed directly, seem

like a kind of landscape, but, from a particular point of sight, they appear very distinctly like human figures.

Reflecting surfaces may be made of various shapes, and, if a regular figure be placed before an irregular reflector the image will be deformed; but, if an object, as a picture, be painted deformed, according to certain rules, the image will appear regular. Such figures and reflectors are sold by opticians, and they serve to astonish those who are ignorant of these subjects.

CONVERSATION XV.

Of the different Parts of the Eye.

CHARLES. Will you now describe the nature and construction of the telescope?

Tutor. I think it will be better first to explain the several parts of the eye, and the nature of vision in the simple state, before we treat of those instruments which are designed to assist it.

James. I once saw a bullock's eye dissected, and was told that it

imitated a human eye in its several parts.

Tutor. The eye, when taken from the socket, is of a globular form, and it is composed of three coats or skins, and three other substances called humours. This figure (Plate III, Fig. 25) represents the section of an eye, that is, an eye cut down the middle; and Fig. 26 the front view of an eye as it appears in the head.

Charles. Have these coats and humours all different names?

Tutor. Yes: the external coat, which is represented by the outer circle A B C D E, is called the *sclerotica*; the front part of this, namely C x D, is perfectly transparent, and is called the *cornea*; beyond this,

towards B and E, it is white, and called the white of the eye. The next coat, which is represented by the second circle, is called the *choroides*.

James. This circle does not go all round.

Tutor. No: the vacant space *a b* is that which we call the pupil, and through this alone the light is allowed to enter the eye.

Charles. What do you call that part which is of a beautiful blue in some persons, and in others brown, or almost black?

Tutor. That, as *a c*, *b e*, is part of the *choroides*, and is called the *iris*.

Charles. The iris is sometimes much larger than it is at another.

Tutor. It is composed of a sort of net-work, which contracts or expands according to the force of the light in which it is placed. Let James stand in a dark corner for two or three minutes:—now look at his eyes.

Charles. The *iris* of each is very small, and the pupil large.

Tutor. Now let him look steadily, rather close to the candle.

Charles. The iris is considerably enlarged, and the pupil of the eye is but a small point in comparison of what it was before.

Tutor. Did you never feel uneasy, after sitting some time in the dark, when candles were suddenly brought into the room?

James. Yes: I remember, last Friday evening, we had been sitting

half an hour almost in the dark at Mr. W——'s, and, when candles were introduced, every one of the company complained of the pain which the sudden light occasioned.

Tutor. By sitting so long in the dark, the iris was contracted very much; of course, the pupil being large, more light was admitted than it could well bear, and, therefore, till time was allowed for the iris to adjust itself, the uneasiness would be felt.

Charles. What do you call the third coat, which, from the figure, appears to be still less than the choroides?

Tutor. It is called the *retina*, or net-work, which serves to receive the images of objects produced by the refraction of the different humours

of the eye, and painted, as it were, on the surface.

Charles. Are the humours of the eye intended for refracting the rays of light in the same manner as glass lenses?

Tutor. They are; and they are called the *vitreous*, the *crystalline*, and the *aqueous* humours. The *vitreous* humour fills up all the space z z, at the back of the eye; it is nearly of the substance of melted glass. The *crystalline* is represented by *d f*, in the shape of a double convex lens: and the *aqueous*, or watery humour, fills up all that part of the eye between the crystalline humour and the corner C *x* D.

James. What does the part A at the back of the eye represent?

Tutor. It is the optic nerve, which

serves to convey to the brain the sensations produced on the retina.

Charles. Does the retina extend to the brain?

Tutor. It does: and we shall, when we meet next, endeavour to explain the office of these humours in effecting vision. In the mean time, I would request you to consider again what I have told you of the different parts of the eye; and examine, at the same time, both figures, *viz.* 25 and 26.

James. We will: but you have said nothing about the uses of the eye-brows and eye-lashes.

Tutor. I intended to have reserved this to another opportunity: but I may now say, that the eye-brows defend the eye from too strong a light; and they prevent the eyes

from injuries by the sliding of substances down the forehead into them.

The eye-lids act like curtains to cover the eyes during sleep; to protect them from accidental violence; to exclude the light when most offensive; and, when we are awake, they diffuse a fluid over the eye, which keeps it clean, and well adapted for transmitting the rays of light.

The eye-lashes, in a thousand instances, guard the eye from danger, and protect it from floating dust, with which the atmosphere abounds.

CONVERSATION XVI.

Of the Eye, and the Manner of Vision.

CHARLES. I do not understand what you meant, when you said, the optic nerve served to convey to the brain the sensations produced on the retina.

Tutor. Nor do I pretend to tell you in what manner the image of any object painted on the retina of the eye is calculated to convey to the mind an idea of that object: but I wish to show you, that the images

of the various objects, which you see, are painted on the retina. Here is a bullock's eye, from the back part of which I cut away the three coats, but so as to leave the vitreous humour perfect: I will now put against the vitreous humour a piece of white paper, and hold the eye towards the window: what do you see?

James. The figure of the window is drawn upon the paper; but it is inverted.

Tutor. Open the window, and you will see the trees in the garden drawn upon it in the same inverted state, or any other bright object that is presented to it.

Charles. Does the paper, in this instance, represent the innermost coat, called the retina?

Tutor. It does; and I have made

use of paper, because it is easily seen through, whereas the retina is opaque; transparency would be of no advantage to it. The retina, by means of the optic nerve, is extended to the brain, or, in other words, the optic nerve is an extension of the retina.

James. And does it carry the news of every object that is painted on the retina?

Tutor. So it should seem; for we have an idea of whatever is drawn upon it. I direct my eyes to you, and the image of your person is painted on the retina of my eye, and I say I see you. So of any thing else.

Charles. You said the rays of light proceeding from external objects were refracted in passing through the different humours of the eye.

Tutor. They are, and converged to a point, or there would be no distinct picture drawn on the retina, and, of course, no distinct idea conveyed to the mind. I will show you what I mean, by a figure, taking an arrow again as an illustration.

As every point of an object A B C (Plate IV, Fig. 27) sends out rays in all directions, some rays, from each point on the side next the eye, will fall upon the cornea between *x y*, and by passing through the humours of the eye, they will be converged, and brought to as many points on the retina, and will form on it a distinct inverted picture *c b a* of the object.

James. This is done in the same manner as you showed us by means of a double convex lens.

Tutor. All three of the humours have some effect in refracting the rays of light, but the crystalline is the most powerful, and that is a complete double convex lens: and you see the rays from A are brought to a point at *a*; those from B will be converged at *b*, and those from C at *c*; and, of course, the intermediate ones between A and B, B and C, will be formed between *a* and *b*, and *b* and *c*. Hence the object becomes visible by means of the image of it being drawn on the retina.

Charles. Since the image is inverted on the retina, how is it that we see things in the proper position?

Tutor. This is a proper question, but one that is not very readily answered. It is well known, that the sense of touch or feeling very much

assists the sense of sight; some paintings are so exquisitely finished, and so much resemble sculpture, that the eye is completely deceived; we then naturally extend the hand to aid the sense of seeing. Children, who have to learn the use of all their senses, make use of their hands in every thing; they see nothing which they do not wish to handle; and, therefore, it is not improbable, that, by the sense of the touch, they learn, unawares, to rectify that of seeing. The image of a chair, or table, or other object, is painted in an inverted position on the retina; they feel and handle it, and find it erect; the same result perpetually recurs, so that, at length, long before they can reason on the subject, or even describe their feelings by speech, the inverted

image gives them an idea of an erect object.

Charles. I can easily conceive that this would be the case with common objects, such as are seen every day and hour. But will there be no difficulty in supposing that the same must happen with regard to any thing which I had never seen before? I never saw ships sailing on the sea till within this month; but when I first saw them they did not appear to me in an inverted position.

Tutor. But you have seen water and land before, and they appear to you, by habit and experience, to be lowermost, though they are painted on the eye in a different position: and the bottom of the ship is next the water, and, consequently, as you refer the water to the bottom, so you must

the hull of the ship which is connected with it. In the same manner all the parts of a distant prospect are right with respect to each other; and, therefore, though there may be a hundred objects in the landscape entirely new to you, yet, as they all bear a relation to one another, and to the earth on which they are, you refer them, by experience, to an erect position.

James. How is it that, in so small a space as the retina of the eye, the images of so many objects can be formed?

Tutor. Dr. Paley* tells us, "The prospect from Hampstead Hill is compressed into the compass of a

* See Paley's Natural Theology, page 35, seventh edition, or page 13 in the Analysis of that work *by the Author of these Dialogues.*

sixpence, yet circumstantially represented. A stage coach, travelling at its ordinary rate, for half an hour, passes, in the eye, only over the twelfth part of an inch, yet the change of place is distinctly perceived throughout its whole progress." Now what he asserts we all know is true: go to the window, and look steadily at the prospect before you, and see how many objects you can discern without moving your eye.

James. I can see a great number very distinctly indeed; besides which I can discern others, on both sides, which are not clearly defined.

Charles. I have another difficulty; we have two eyes, on both of which the images of objects are painted, how is it that we do not see every object double?

Tutor. When an object is seen distinctly with both eyes, the *axes* of them are directed to it, and the object appears single; for the optic nerves are so framed, that the correspondent parts, in both eyes, lead to the same place in the brain, and excite but one sensation. But, if the axes of both eyes are not directed to the object, that object seems double.

James. How does that appear?

Tutor. Look at your brother, while I push your right eye out of its place towards the left.

James. I see two brothers, the one receding to the left hand of the other.

Tutor. The reason is this; by pushing the eye out of its natural place, the pictures in the two eyes do not fall upon correspondent parts of the retina, and therefore the sen-

sations from each eye are excited in different parts of the brain. When any point of an object is seen distinctly with both eyes, the axes of both are directed to that point, and meet there, and then the object appears single, though looked at with both eyes.

CONVERSATION XVII.

Of Spectacles, and of their Uses.

CHARLES. Why do people wear spectacles?

Tutor. To assist the sight, which may be defective from various causes. Some eyes are too flat, others are too convex: in some the humours lose a part of their transparency, and on that account a deal of light that enters the eye is stopt and lost in the passage, and every object appears dim. The eye, without light, would be a useless machine. Spectacles are

intended to collect the light, or to bring it to a proper degree of convergency.

Charles. Are spectacle-glasses always convex?

Tutor. No: they are convex when the eyes are too flat; but, if the eyes are already very convex, then concave glasses are used. You know the properties of a convex glass?

James. Yes; it is to make the rays of light converge sooner than they would without.

Tutor. Suppose, then, a person is unable to see objects distinctly, owing to the cornea C D (Plate IV, Fig. 28), or to the crystalline *a b*, or both, being too flat. The focus of rays proceeding from any object, *x*, will not be on the retina,

where it ought to be, but at *z*, beyond it.

Charles. How can it be beyond the eye?

Tutor. It would be beyond it, if there were any thing to receive it; as it is, the rays flowing from *x* will not unite at *d*, so as to render vision distinct. To remedy this, a convex glass *mn* is placed between the object and the eye, by means of which the rays are brought to a focus sooner, and the image is formed at *d*.

James. Now I see the reason why people are obliged, sometimes, to make trial of many pairs of spectacles before they get those that will suit them. They cannot tell exactly what degree of convexity is necessary to bring the focus just to the retina.

Tutor. That is right; for the

shape of the eye may vary as much as that of their countenance; of course, a pair of spectacles, that might suit you, would not be adapted to another, whose eyes should require a similar aid—What is the property of concave glasses?

Charles. They cause the rays of light to diverge.

Tutor. Then, for very round and globular eyes, these will be useful, because, if the cornea C D, or crystalline *a b* (Plate IV, Fig. 29), be too convex, the rays flowing from *x* will unite into a focus before they arrive at the retina, as at *z*.

Charles. If the sight then depend on sensations produced on the retina, such a person will not see the object at all, because the image of it does not reach the retina.

Tutor. True: but at *z* the rays cross one another, and pass on to the retina, where they will produce some sensations, but not those of distinct vision, because they are not brought to a focus there. To remedy this, the concave glass *m n* is interposed between the object and the eye, which causes the rays coming to the eye, to *diverge;* and, being more divergent when they enter the eye, it requires a very convex cornea or crystalline, to bring them to a focus at the retina.

James. I have seen old people, when examining an object, hold it a good distance from their eyes.

Tutor. Because, their eyes being too flat, the focus is thrown beyond the eye, and therefore they hold the

object at a distance to bring the focus z (Fig. 28) to the retina.

Charles. Very short-sighted people bring objects close to their eyes.

Tutor. Yes; I once knew a young man, who was apt, in looking at his paper, to rub out with his nose what he had written with his pen. In this case, bringing the object near the eye produces a similar effect to that produced by concave glasses; because, the nearer the object is brought to the eye, the greater is the angle under which it is seen; that is, the extreme rays, and, of course, all the others, are made more divergent.

James. I do not understand this.

Tutor. Well, let E be the eye (Plate IV, Fig. 30), and the object *a b* seen at z, and also at x, double the

distance; will not the same object appear under different angles to an eye so situated?

James. Yes, certainly *a* E *b* will be larger than *c* E *d*, and will include it.

Tutor. Then the object being brought very near the eye has the same effect as magnifying the object, or of causing the rays to diverge; that is, though *a b* and *c d* are of the same lengths, yet *a b* being nearest to the eye, will appear the largest.

Charles. You say the eyes of old people become flat by age, is that the natural progress?

Tutor. It is; and therefore people, who are very short-sighted while young, will probably see well when they grow

James. That is an advantage denied to common eyes.

Tutor. But people, blessed with common sight, should be thankful for the benefit they derived while young.

Charles. And I am sure we cannot too highly estimate the science of optics, that has afforded such assistance to defective eyes, which, in many circumstances of life, would be useless without them.

Tutor. Spectacles were known and used long before the principle of the microscope and telescope was brought into action. Salvinus Armatus, a nobleman of Florence, claimed the honour of the invention of spectacles: he died in 1317, and the fact was inscribed on his tomb. But it is generally believed that Alhazen was the real inventor, 50 or 60 years prior to this period.

CONVERSATION XVIII.

Of the Rainbow.

TUTOR. You have frequently seen a rainbow?

Charles. Oh yes, and very often there are two at the same time, one above the other; the lower one is by far the most brilliant.

Tutor. This is, perhaps, the most beautiful meteor in nature; it never makes its appearance but when a spectator is situated between the sun

and the shower. It is thus described by Thomson:—

——Reflected from yon eastern cloud,
Bestriding earth, the grand ethereal bow
Shoots up immense; and every hue unfolds,
In fair proportion, running from the red
To where the vi'let fades into the sky.
Here, awful Newton, the dissolving clouds
Form, fronting on the sun, thy show'ry prism;
And to the sage-instructed eye unfold
The various twine of light, by thee disclos'd
From the white mingling maze.

James. Is a rainbow occasioned by the falling drops of rain?

Tutor. Yes, it depends on the reflection and refraction of the rays of the sun by the falling drops.

Charles. I know now how the rays of the sun are *refracted* by water, but are they *reflected* by it also?

Tutor. Yes; water, like glass, reflects some rays, while it transmits or refracts others. You know the beauty of the rainbow consists in its colours.

James. Yes; "the colours of the rainbow" is a very common expression; I have been told there are seven of them, but it is seldom that so many can be clearly distinguished.

Tutor. Perhaps that is owing to your want of patience; I will show you the colours first by means of the prism. If a ray of light S (Plate V, Fig. 31) be admitted into a darkened room, through a small hole in the shutter *x y*, its natural course is along the line to *d*; but if a glass prism *a c* be introduced, the whole ray will be bent upwards; and, if it be taken on any white surface, as M N, it will form

an oblong image P T, the breadth of which is equal to the diameter of the hole in the shutter.

Charles. This oblong is of different colours in different parts.

Tutor. These are the colours of the rainbow, which are described by Dr. Darwin as *untwisted* :—

Next with illumin'd hands through prisms bright
Pleas'd they untwist the sevenfold threads of light;
Or, bent in pencils by the lens, convey
To one bright point the silver hairs of day.

James. But how is the light, which is admitted by a *circular* hole in the window, spread out into an oblong?

Tutor. If the ray were of one substance, it would be equally bent upwards, and make only a small cir-

cular image. Since, therefore, the image or picture is oblong, it is inferred, that it is formed of rays, differently refrangible, some of which are turned more out of the way, or more upwards than others; those which go to the upper part of the spectrum being most refrangible, those which go to the lowest part are the least refrangible, the intermediate ones posses more or less refrangibility, according as they are painted on the spectrum. Do you see the seven colours?

Charles. Yes, here is the *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*.

Tutor. These colours will be still more beautiful, if a convex lens be interposed, at a proper distance, between the shutter and the prism.

James. How does this apply to the rainbow?

Tutor. Suppose A (Plate V, Fig. 32) to be a drop of rain, and S *d* a ray from the sun falling upon or entering it at *d*, it will not go to *c*, but be refracted to *n*, where a part will go out, but a part also will be reflected to *q*, where it will go out of the drop, which acting like a prism, separates the ray into its primitive colours; the violet will be uppermost, the red lowermost.

Charles. Is it at any particular angle that these colours are formed?

Tutor. Yes, they are all at fixed angles; the least refrangible, or red, makes an angle with the solar incident ray, equal to little more than 42 degrees; and the violet, or most refrangible, ray, will make with the solar ray an angle of 40 degrees.

James. I do not understand which are these angles.

Tutor. The ray s *d* would go to *f c*, therefore the angle made with the red ray is s *f q*, and that made with the violet ray is s *c q*; the former 42° 2′, the latter 40° 17′.

Charles. Is this always the case, be the sun either high or low in the heavens?

Tutor. It is; but the situation of the rainbow will vary, accordingly as the sun is high or low; that is, the higher the sun, the lower will be the rainbow: a shower has been seen on a mountain by a spectator in a valley, by which a complete circular rainbow has been exhibited.

James. And I once remember standing on Morant's Court Hill, in Kent, when there was a heavy shower,

while the sun shone very bright, and all the landscape beneath, to a vast extent, seemed to be painted with the prismatic colours.

Tutor. I recollect this well; and perhaps to some such scenes Thomson alludes: it was certainly the most beautiful one I ever beheld:—

These, when the clouds distil the rosy shower,
Shine out distinct adown the *watery bow;*
While o'er our heads the dewy vision bends
Delightful, melting on the fields beneath.
Myriads of mingling dies from these result,
And myriads still remain; infinite source
Of beauty, ever blushing, ever new.

Charles. You have not explained the principles of the upper or fainter bow.

Tutor. This is formed by two refractions and two reflections: suppose the ray T *r* to be entering the

drop B at *r*. It is refracted at *r*, reflected at s, reflected again at *t*, and refracted as it goes out at *u*, whence it proceeds, being separated, to the spectator at *g*. Here the colours are reversed; the angle formed by the red ray is 51°, and that formed by violet is 54°.

James. Does the same thing happen with regard to a whole shower, as you have shown with respect to the two drops?

Tutor. Certainly, and by the constant falling of the rain, the image is preserved constant and perfect. Here is the representation of the two bows. (Plate V, Fig. 33.) The rays come in the direction S A, and the spectator stands at E, with his back to the sun, or, in other words, he must be between the sun and the shower.

This subject may be shown in another way; if a glass globule filled with water be hung sufficiently high before you, when the sun is behind, to appear red, let it descend gradually, and you will see in the descent all the other six colours follow one another. Artificial rainbows may be made with a common watering pot, but much better with a syringe fixed to an artificial fountain; and I have seen one by spirting up water from the mouth: it is often seen in cascades, in the foaming of the waves of the sea, in fountains, and even in the dew on the grass.

Dr. Langwith has described a rainbow, which he saw lying on the ground, the colours of which were almost as lively as those of the com-

mon rainbow. It was extended several hundred yards, and the colours were so strong, that it might have been seen much farther, if it had not been terminated by a bank, and the hedge of a field.

Rainbows have also been produced by the reflection of the sun's beams from a river: and Mr. Edwards describes one, which must have been formed by the exhalations from the city of London, when the sun had been set twenty minutes*.

* See Phil. Trans. Vols. VI and L.

CONVERSATION XIX.

Of the Refracting Telescope.

TUTOR. We now come to describe the structure of telescopes, of which there are two kinds; *viz.* the *refracting* and the *reflecting* telescope.

Charles. The former, or *refracting* telescope, depends, I suppose, upon *lenses* for the operation; and the *reflecting* telescope acts chiefly by means of *mirrors*.

Tutor. These are the general principles upon which they are formed;

and we shall devote this morning to the explanation of the *refracting* telescope. Here is one completely fitted up.

James. It consists of two tubes and two glasses.

Tutor. The tubes are intended to hold the glasses, and to confine the boundary of the view. I will therefore explain the principle by the following figure (Plate V. Fig. 34), in which is represented the eye A B, the two lenses, *m n*, *o p*, and the object, *x y*. The lens *o p*, which is nearest to the object, is called the object-glass, and that *m n*, nearest to the eye, is called the eye-glass.

Charles. Is the object-glass a double convex, and the eye-glass a double concave?

Tutor. It happens so in this particular instance, but it is not necessary that the eye-glass should be concave; the object-glass must, however, in all cases, be convex.

Charles. I see exactly, from the figure, why the eye-glass is concave: for the convex lens converges the rays too quickly, and the focus by that glass alone would be at E: and therefore the concave is put near the eye to make the rays diverge so much as to throw them to the retina before they come to a focus.

Tutor. But that is not the only reason: by coming to a focus at E, the image is very small, in comparison of what it is when the image is formed on the retina, by means of the concave lens. Can you, James, explain

the reason of all the lines which you see in the figure?

James. I think I can;—there are two pencils of rays flowing from the extremities of the arrow, which is the object to be viewed. The rays of the pencil flowing from *x* go on diverging till they reach the convex lens *o p*, when they will be so refracted, by passing through the glass, as to converge, and meet in the point *x*. Now the same may be said of the pencil of rays which come from *y*; and, of course, of all the pencils of rays flowing from the object between *x* and *y*. So that the image of the arrow would, by the convex lens, be formed at E.

Tutor. And what would happen if there were no other glass?

James. The rays would cross each

other, and be divergent, so that when they got to the retina there would be no distinct image formed, but every point, as x or y, would be spread over a large space, and the image would be confused. To prevent this, the concave lens $m\ n$ is interposed; the pencil of rays, which would, by the convex glass, converge at x, will now be made to diverge, so as not to come to a focus till they arrive at the retina: and the pencil of rays which would, by the convex glass, have come to a point at y, will, by the interposition of the concave lens, be made to diverge so much as to throw the focus of the rays to b instead of y. By this means, the image of the obj ect is magnified.

Tutor. Can you tell the reason why the tubes require to be drawn

out more or less for different persons?

Charles. The tubes are to be adjusted, in order to throw the focus of rays exactly on the retina: and, as some eyes are more convex than others, the length of the focus will vary in different persons; and, by sliding the tube up or down, this object is obtained.

Tutor. Refracting telescopes are used chiefly for viewing the terrestrial objects; two things, therefore, are requisite in them; the *first* is, that they should show objects in an upright position, that is, in the same position as we see them without glasses; and the second is, that they should afford a large *field of view.*

James. What do you mean, Sir, by a field of view?

Tutor. All that part of landscape which may be seen at once, without moving the eye or instrument. Now, in looking on the figure again, you will perceive, that the concave lens throws a number of the rays beyond the pupil c of the eye, on to the iris on both sides, but those only are visible, or go to form an image, which pass through the pupil; and, therefore, by a telescope made in this way, the middle part of the object is only seen, or, in other words, the prospect is by it very much diminished.

Charles. How is that remedied?

Tutor. By substituting a double convex eye-glass *g h* (Plate V, Fig. 35) instead of the concave one. Here the focus of the double convex lens is at E, and the glass *g h* must be so much more convex than *o p*,

as that its focus may be also at E; for then the rays flowing from the object *x y*, and passing through the object-glass *o p*, will form the inverted image *m* E *d*. Now, by interposing the double convex *g h*, the image is thrown on the retina, and it is seen under the large angle D *e* C; that is, the image *m* E *d* will be magnified to the size C E D.

James. Is not the image of the object in the telescope inverted?

Tutor. Yes, it is: for you see the image on the retina stands in the same position as the object; but we always see things by having the images inverted: and, therefore, whatever is seen by telescopes, constructed as this is, will appear inverted to the spectator, which is a very unpleasant circumstance with

regard to terrestrial objects; it is on that account chiefly used for celestial observations.

Charles. Is there any rule for calculating the magnifying power of this telescope?

Tutor. It magnifies in proportion as the focal distance of the object-glass is greater than the focal distance of the eye-glass. Thus, if the focal distance of the object-glass is ten inches, and that of the eye-glass only a single inch, the telescope magnifies the *diameter* of an object ten times: and the *whole surface* of the object will be magnified a hundred times.

Charles. Will a small object, as a silver penny for instance, appear a hundred times larger through this telescope than it would by the naked eye?

Tutor. Telescopes, in general, represent terrestrial objects to be *nearer* and not *larger*: thus, looking at the silver penny a hundred yards distant, it will not appear to be larger, but at the distance only of a single yard.

James. Is there no advantage gained, if the focal distance of the eye-glass, and of the object-glass, be equal?

Tutor. None; and therefore in telescopes of this kind we have only to increase the focal distance of the object-glass, and to diminish the focal distance of the eye-glass, to augment the magnifying power to almost any degree.

Charles. Can you carry this principle to any extent?

Tutor. Not altogether so: an ob-

ject-glass of ten feet focal distance, will require an eye-glass whose focal distance is rather more than two inches and a half; and an object-glass with a focal distance of a hundred feet, must have an eye-glass whose focus must be about six inches from it. How much will each of these glasses magnify?

Charles. Ten feet divided by two inches and a half give for a quotient forty-eight: and a hundred feet divided by six inches give two hundred: so that the former magnifies 48 times, and the latter 200 times.

Tutor. Refracting telescopes, for viewing terrestrial objects, in order to show them in their natural posture, are usually constructed with one object-glass, and three eye-glasses, the

focal distances of these last being equal.

James. Do you make use of the same method in calculating the magnifying power of a telescope constructed in this way, as you did in the last?

Tutor. Yes; the three glasses next the eye having their focal distances equal, the magnifying power is found by dividing the focal distance of the object-glass by the focal distance of one of the eye-glasses. We have now said as much on the subject as is necessary to our plan.

Charles. What is the construction of opera-glasses, that are so much used at the theatre?

Tutor. The opera-glass is nothing more than a short refracting telescope.

The *night* telescope is only about two feet long; it represents objects inverted, much enlightened, but not greatly magnified. It is used to discover objects, not very distant, but which cannot otherwise be seen, for want of sufficient light.

The night telescope is much used in observations on eclipses of the moon. Directions are given to the young astronomer, with regard to the use of this instrument, in Vince's Practical Astronomy, in which we learn, that the late Dr. Maskelyne used to advise the observer to place a circular aperture at the object end, about half the size of the common aperture.

CONVERSATION XX.

Of Reflecting Telescopes.

TUTOR. This is a telescope of a different kind, and is called a *reflecting* telescope.

Charles. What advantage does the reflecting telescope possess over that which you described yesterday?

Tutor. The great inconvenience attending refracting telescopes is their length, and, on that account, they are not very much used when high powers are required. A reflector of six

feet long will magnify as much as a refractor of a hundred feet.

James. Are these, like the refracting telescopes, made in different ways?

Tutor. They were invented by Sir Isaac Newton, but have been greatly improved since his time. The following figure (Plate VI, Fig. 36) will lead to a description of one of those most in use. You know that there is a great similarity between *convex lenses* and *concave mirrors*.

Charles. They both form an inverted focal image of any remote object, by the convergence of the pencils of rays.

Tutor. In instruments, the exhibitions of which are the effects of reflection, the concave mirror is substituted for the convex lens. T T

(Fig. 36) represents the large tube, and *t t* the small tube of the telescope, at one end of which is D F, a concave mirror, with a hole in the middle at P, the principal focus of which is at I K; opposite to the hole P is a small mirror L, concave towards the great one; it is fixed on a strong wire M, and may, by means of a long screw on the outside of the tube, be made to move backwards or forwards. A B is a remote object; from which rays will flow to the great mirror D F.

James. And I see you have taken only two rays of a pencil from the top and two from the bottom.

Tutor. And, in order to trace the progress of the reflections and refractions, the upper ones are represented by full lines, the lower ones by dotted

lines. Now the rays at C and E, falling upon the mirror at D and F, are reflected, and form an inverted image at *m*.

Charles. Is there any thing there to receive the image?

Tutor. No: and therefore they go on towards the reflector L, the rays from different parts of the object crossing one another a little before they reach L.

James. Does not the hole at P tend to distort the image?

Tutor. Not at all; the only defect is, that there is less light. From the mirror L the rays are reflected nearly parallel through P, there they have to pass the plano-convex lens R, which causes them to converge at *a b*, and the image is now painted in the small tube near the eye.

Charles. What is the other plano-convex len s for?

Tutor. Having, by means of the lens R, and the two concave mirrors, brought the image of the object so nigh as at *a b*, we only want to magnify the image.

James. This, I see, is done by the lens S.

Tutor. It is, and will appear as large as *c d*, that is, the image is seen under the angle *c f d*.

Charles. How do you estimate the magnifying power of the reflecting telescope?

Tutor. The rule is this: "Multiply the focal distance of the large mirror by the distance of the small mirror from the image *m*: then multiply the focal distance of the small mirror by the focal distance of the

eye-glass; and divide these two products by one another, and the quotient is the magnifying power.

James. It is not likely that we should know all these in any instrument we possess.

Tutor. The following, then, is a method of finding the same thing by experiment. "Observe at what distance you can read any book with the naked eye, and then remove the book to the farthest distance at which you can distinctly read by means of the telescope, and divide the latter by the former."

The powers of different telescopes may be readily tried and compared, by looking at double stars, and observing whether, and how far, they separate them. This refers to telescopes of high powers.

Charles. Has not Dr. Herschel a very large reflecting telescope?

Tutor. He has made many, but the tube of the grand telescope is nearly 40 feet long, and 4 feet 10 inches in diameter. The concave surface of the great mirror is 48 inches, of polished surface, in diameter, and it magnifies 6000 times. This noble instrument cost the Doctor four years' severe labour: it was finished August 28, 1789, on which day was discovered the sixth satellite of Saturn:—

Delighted Herschel, with reflected light,
Pursues his radiant journey through the night,
Detects new guards, that roll their orbs afar,
In lucid ringlets round the Georgian star.

DARWIN.

CONVERSATION XXI.

Of the Microscope—Its Principle—Of the Single Microscope—Of the Compound Microscope—Of the Solar Microscope.

TUTOR. We are now to describe the microscope, which is an instrument for viewing very small objects. You know, that, in general, persons who have good sight, cannot distinctly view an object at a nearer distance than about six inches.

Charles. I cannot read a book at a shorter distance than this; but, if I

look through a small hole made with a pin or needle in a sheet of brown paper, I can read at a very small distance indeed.

Tutor. You mean, that the letters appear, in that case, very much magnified, the reason of which is, that you are able to see at a much shorter distance in this way than you can without the intervention of the paper. Whatever instrument, or contrivance, can render minute objects visible and distinct is properly a microscope.

James. If I look through the hole in the paper, at the distance of five or six inches from the print, it is not magnified.

Tutor. The object must be brought near to increase the angle by which it is seen; this is the principle of all mi-

croscopes, from the single lens to the most compound instrument. A (Plate VI, Fig. 37) is an object not clearly visible at a less distance than A B; but, if the same object be placed in the focus C (Fig. 38) of the lens D, the rays which proceed from it will become parallel, by passing through the said lens, and therefore the object is distinctly visible to the eye at E, placed any where before the lens. There are three distinctions in microscopes; the single, the compound, and the solar.

Charles. Does the single microscope consist only of a lens?

Tutor. By means of a lens, a great number of rays, proceeding from a point, are united in the same sensible point, and, as each ray carries with it the image of the point from whence

it proceeded, all the rays united must form an image of the object.

James. Is the image *brighter* in proportion as there are more rays united?

Tutor. Certainly: and it is more distinct in proportion as their natural order is preserved. In other words, a single microscope or lens removes the confusion, that accompanies objects when seen very near by the naked eye: and it magnifies the diameter of the object, in proportion as the focal distance is less than the limit of distinct vision, which we may reckon from about six to eight inches.

Charles. If the focal distance of a reading-glass be four inches, does it magnify the diameter of each letter only twice?

Tutor. Exactly so: but the lenses used in microscopes are often not more than $\frac{1}{4}$, or $\frac{1}{8}$, or even $\frac{1}{20}$ part of an inch radius.

James. And, in a double convex, the focal distance is always equal to the radius of convexity.

Tutor. Then tell me how much lenses of $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{20}$ of an inch will each magnify?

James. That is readily done: by dividing 8 inches, the limit of distinct vision, by $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{20}$.

Charles. And to divide a whole number, as 8, by a fraction, as $\frac{1}{4}$, &c. is to multiply the said number by the denominator of the fraction: of course, 8 multiplied by 4 gives 32; that is, the lens whose radius is a $\frac{1}{4}$ of an inch, magnifies the diameter of the object 32 times.

James. Therefore the lenses, of which the radii are $\frac{1}{8}$ and $\frac{1}{20}$, will magnify as 8 multiplied by 8, and 8 multiplied by 20: that is, the former will magnify 64 times, the latter 160 times, the diameter of an object.

Tutor. You see, then, that the smaller the lens, the greater its magnifying power. Dr. Hooke says, in his work on the microscope, that he has made lenses so small, as to be able, not only to distinguish the particles of bodies a million times smaller than a visible point, but even to make those visible of which a million times a million would hardly be equal to the bulk of the smallest grain of sand.

Charles. I wonder how he made them.

Tutor. I will give you his description: he first took a very narrow and thin slip of clear glass, melted it in the flame of a candle or lamp, and drew it out into exceedingly fine threads. The end of one of these threads he melted again in the flame, till it run into a very small drop, which, when cool, he fixed in a thin plate of metal, so that the middle of it might be directly over the centre of an extremely small hole made in the plate. Here is a very convenient single microscope.

James. It does not seem, at first sight, so simple as those which you have just now described.

Tutor. A (Fig. 39) is a circular piece of brass, it may be made of wood, ivory, &c., in the middle of which is a very small hole; in this is

fixed a small lens, the focal distance of which is A D; at that distance is a pair of pliers D E, which may be adjusted by the sliding screw, and opened by means of two little studs *a e;* with these any small object may be taken up, and viewed with the eye placed at the other focus of the lens at F, to which it will appear magnified, as at I M.

Charles. I see, by the joint, it is made to fold up.

Tutor. It is; and may be put into a case, and carried about in the pocket, without any incumbrance or inconvenience. Let us now look at a double, or compound microscope.

James. How many glasses are there in this?

Tutor. There are two; and the construction of it may be seen by this

figure; *c d* (Fig. 40) is called the object-glass, and *e f* the eye-glass. The small object *a b* is placed a little farther from the glass *c d* than its principal focus, so that the pencils of rays, flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed. This image is viewed by the eye-glass *e f*, which is so placed that the image *g h* may be in the focus, and the eye at about an equal distance on the other side; the rays of each pencil will be parallel, after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k*, by the humours of which they will be converged and collect ed into points on the retina,

and form the large inverted image A B.

Charles. Pray, Sir, how do you calculate the magnifying power of this microscope?

Tutor. There are two proportions, which, when found, are to be multiplied into one another: (1) As the distance of the image from the object-glass is *greater* than its distance from the eye-glass; and (2) as the distance from the object is *less* than the limit of distinct vision*.

Example. If the distance of the

* Dr. Vince gives the following rule for finding the linear magnifying power of a compound microscope: "It is equal to the least distance of distinct vision, multiplied by the distance of the image from the object-glass, divided by the distance of the object from the object-glass, multiplied by the focal length of the eye-glass."

image from the object-glass be 4 times greater than from the eye-glass, the magnifying power of 4 is gained; and, if the focal distance of the eye-glass be one inch, and the distance of distinct vision be considered at 7 inches, the magnifying power of 7 is gained, and 7×4 gives 28; that is, the diameter of the object will be magnified 28 times, and the surface will be magnified 784 times.

James. Do you mean, that an object will, through such a microscope, appear 784 times larger than by the naked eye?

Tutor. Yes, I do; provided the limit of distinct vision be 7 inches; but some persons who are short-sighted, can see as distinctly at 5 or 4 inches, as another can at 7 or 8:

to the former the object will not appear so large as to the latter.

Example 2. What will a microscope of this kind magnify to three different persons, whose eyes are so formed as to see distinctly at the distance of 6, 7, and 8 inches, by the naked eye: supposing the image of the object-glass to be five times as distant as from the eye glass, and the focal distance of the eye-glass be only the tenth part of an inch?

Charles. As five is gained by the distances between the glasses, and 60, 70, and 80, by the eye-glass, the magnifying powers will be as 300, 350, and 400.

James. How is it 60, 70, and 80, are gained by the eye-glass?

Charles. Because the distances of distinct vision are put at 6, 7, and 8

inches, and these are to be divided by the focal distance of the eye-glass, or by $\frac{1}{10}$; but, to divide a whole number by a fraction, we must multiply that number by the denominator, or lower figure in the fraction: therefore, the power gained by the distance between the two glasses, or 5, must be multiplied by 60, 70, or 80. And the surface of the object will be magnified in proportion to the square of 300, 350, or 400, that is, as 90,000, 122,500, or 160,000.

Tutor. We now come to the solar microscope, which is by far the most entertaining of them all, because the image is much larger, and, being thrown on a sheet, or other white surface, may be viewed by many spectators at the same time, without any fatigue to the eye. Here is one

fixed in the window-shutter, but I can explain its construction best by a figure.

James. There is a looking-glass on the outside of the window.

Tutor. Yes, the solar microscope consists (Plate VI, Fig. 42) of a looking-glass s o without, the lens *a b* in the shutter *d u*, and the lens *n m* within the dark room. These three parts are united to and in a brass tube. The looking-glass can be turned by the adjusting screw, so as to receive the incident rays of the sun *s s s*, and reflect them through the tube into the room. The lens *a b* collects those rays into a focus at *n m*, where there is another magnifier; here, of course, the rays cross, and diverge to the white screen, on which the image of the object will be painted.

Charles. I see the object is placed a little behind the focus.

Tutor. If it were in the focus it would be burnt to pieces immediately. The magnifying power of this instrument depends on the distance of the sheet, or white screen; perhaps about 10 feet is as good a distance as any. You perceive, that the size of the image is to that of the object, as the distance of the former from the lens *n m* is to that of the latter.

James. Then the nearer the object to the lens, and the farther the screen from it, the greater the power of this microscope.

Tutor. You are right; and, if the object be only half an inch from the lens, and the screen nine feet, the image will be 46,656 times larger

than the object: do you understand this?

Charles. Yes, the object being only half an inch from the lens, and the image 9 feet or 108 inches, or 216 half inches, the diameter of the image will be 216 times larger than the diameter of the object, and this number multiplied into itself will give 46,656.

Tutor. This instrument is calculated only to exhibit transparent objects, or such as the light can pass through in part. For opaque objects, a different microscope is used: and, indeed, there are an indefinite number of microscopes*, and of

* The reader is referred to the author's "Dialogues on the Microscope," which may be had of the publishers of this work.

them all we may say, though in different degrees: —

The artificial convex will reveal
The forms diminutive, that each conceal;
Some, so minute, that, to the one extreme,
The mite a vast leviathan would seem;
That yet of organs, functions, sense partake,
Equal with animals of larger make.
In curious limbs and clothing they surpass
By far the comeliest of the bulky mass.
A world of beauties! that thro' all this frame
Creation's grandest miracles proclaim.

BROWNE.

CONVERSATION XXII.

Of the Camera Obscura, Magic Lanthorn, and Multiplying Glass.

TUTOR. We shall now treat upon some miscellaneous subjects; of which the first shall be the *Camera Obscura*.

Charles. What is a camera obscura?

Tutor. The meaning of the term is a darkened chamber: the construction of it is very simple, and will be understood in a moment by you, who

know the properties of the convex lens.

A convex lens, placed in a hole of a window-shutter, will exhibit, on a white sheet of paper placed in the focus of the glass, all the objects on the outside, as fields, trees, men, houses, &c., in an inverted order.

James. Is the room to be quite dark, except the light which is admitted through the lens?

Tutor. It ought to be so; and, to have a very interesting picture, the sun should shine upon the objects.

James. Is there no other kind of camera obscura?

Tutor. A portable one may be made with a square box, in one side of which is to be fixed a tube, having a convex lens in it: within the box is a plane mirror reclining backwards

from the tube, in an angle of forty-five degrees.

Charles. On what does this mirror reflect the image of the object?

Tutor. The top of the box is a square of unpolished glass, on which the picture is formed. And, if a piece of oiled paper be stretched on the glass, a landscape may be easily copied: or the outline may be sketched on the rough surface of the glass.

James. Why is the mirror to be placed at an angle of 45 degrees exactly?

Tutor. The image of the objects would naturally be formed at the back of the box opposite to the lens: in order, therefore, to throw it on the top, the mirror must be

so placed that the angle of incidence shall be equal to the angle of reflection. In the box, according to its original make, the top is at right angles to the end, that is, at an angle of 90 degrees, therefore the mirror is put at half 90, or 45 degrees.

Charles. Now the incident rays falling upon a surface, which declines to an angle of 45 degrees, will be reflected at an equal angle of 45 degrees, which is the angle that the glass top of the box bears with respect to the mirror.

James. If I understand you clearly, had the mirror been placed at the end of the box, or parallel to it, the rays would have been reflected back to the lens; and none

would have proceeded to the top of the box.

Tutor. True: in the same manner as when one person stands before a looking-glass, another at the side of the room cannot see his image in the glass, because the rays, flowing from him to the looking-glass, are thrown back to himself again; but let each person stand on the opposite side of the room, while the glass is in the middle of the end of it, they will both stand at an angle of 45 degrees, with regard to the glass, and the rays from each will be reflected to the other.

Charles. Is the tube fixed in this machine?

Tutor. No; it is made to draw out, or push in, so as to adjust the distance of the convex glass from

the mirror, in proportion to the distance of the outward objects, till they are distinctly painted on the horizontal glass.

James. Will you now explain the structure of the magic lanthorn, which has long afforded us occasional amusement?

Tutor. This little machine consists, as you know, of a sort of tin box; within which is a lamp or candle, the light of this passes through a great plano-convex lens, placed in a tube fixed in the front. This strongly illuminates the objects which are painted on slips of glass, and placed before the lens in an inverted position. A sheet, or other white surface, is placed to receive the images.

Charles. Do you invert the glasses

on which the figures are drawn, in order that the images of them may be erect?

Tutor. Yes, and the illumination may be greatly increased, and the effect much more powerful, by placing a concave mirror at the back of the lamp.

Charles. Did you not tell us that the *Phantasmagoria*, which we saw at the Lyceum, was a species of the magic lanthorn?

Tutor. There is this difference between them: in common magic lanthorns, the figures are painted on transparent glass, consequently the image on the screen is a circle of light having a figure or figures on it; but in the Phantasmagoria, all the glass is made opaque, except the figure only, which, being painted in

transparent colours, the light shines through it, and no light can come upon the screen but what passes through the figure.

James. But there was no sheet to receive the picture.

Tutor. No: the representation was thrown on a thin screen of silk placed between the spectators and the lanthorn.

Charles. What caused the images to appear approaching and receding?

Tutor. It is owing to removing the lanthorn farther from the screen, or bringing it nearer to it; for the size of the image must increase as the lanthorn is carried back, because the rays come in the shape of a cone; and, as no part of the screen is visible, the figure appears to be

formed in the air, and to move farther off when it becomes smaller, and to come nearer as it increases in size.

James. Here is another instrument, the construction of which you promised to explain: the *multiplying glass.*

Tutor. One side of this glass is cut into many distinct surfaces, and in looking at an object, as your brother, through it, you will see, not one object only, but as many as the glass contains plane surfaces.

I will draw a figure to illustrate this: let (Plate VI, Fig. 42) A *i* B represent a glass, flat at the side, next the eye H, and cut into three distinct surfaces on the opposite side, as A *b*, *b d*, *d* B. The object C will not appear magnified, but, as rays

will flow from it to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye in the direction of the rays, which enter it through each surface. Thus a ray C *i*, falling perpendicularly on the middle surface, will suffer no refraction, but show the object in its true place at C: the ray from C *b*, falling obliquely on the plane surface A *b*, will be refracted in the direction *b e*, and, on leaving the glass at *e*, it will pass to the eye in the direction *e* H, and therefore it appears at E; and the ray C *d* will, for the same reason, be refracted to the eye in the direction B H, and the object C will appear also in D.

If, instead of three sides, the glass

had been cut into 6, or 20, or any other number, there would have appeared 6, 20, &c. different objects, differently situated.

MAGNETISM.

CONVERSATION I.

Of the Magnet—Its Properties—Useful to Mariners, and others—Iron rendered Magnetic—Properties of the Magnet.

TUTOR. You see this dark-brown mineral body, it is almost black, and you know it has the property of attracting needles and other small iron substances.

James. Yes, it is called a load-stone, leading-stone, or magnet; we

have often been amused with it: but you told us that it possessed a much more important property than that of attracting iron and steel.

Tutor. This is what is called the *directive property*, by which mariners are enabled to conduct their vessels through the mighty ocean out of the sight of land; by the aid of this, miners are guided in their subterranean inquiries, and the traveller through deserts otherwise impassable.

Charles. Were not mariners unable to make long and very distant voyages till this property of the magnet was discovered?

Tutor. Till then they contented themselves with mere coasting voyages; seldom trusting themselves from the sight of land.

James. How long is it since this

property of the magnet was first known?

Tutor. About five hundred years; and it is not possible to ascertain, with any degree of precision, to whom we are indebted for this great discovery.

Charles. You have not told us in what the discovery consists.

Tutor. When a magnet, or a needle rubbed with a magnet, is freely suspended, it will always, and in all places, stand nearly north and south.

Charles. Is it known which end points to the north, and which to the south?

Tutor. Yes: or it would be of little use: each magnet, and each needle, or other piece of iron, that is made an *artificial* magnet by being properly rubbed with the *natural*

magnet, has a north end and a south end, called the *north* and *south poles:* to the former a mark is placed, for the purpose of distinguishing it.

James. Then, if a ship were to make a voyage to the north, it must follow the direction which the magnet takes.

Tutor. True; and if it were bound a westerly course, the needle always pointing north, the ship must keep in a direction at right angles to the needle. In other words, the direction of the needle must be across the *ship.*

Charles. Could not the same object be obtained by means of the pole star?

Tutor. It might, in a considerable degree, provided you could always ensure a fine clear sky; but

what is to be done in cloudy weather, which in some latitudes will last for many days together?

Charles. I did not think of that.

Tutor. Without the use of the magnet, no persons could have ventured upon such voyages as those to the West Indies, and other distant parts; the knowledge, therefore, of this instrument cannot be too highly prized.

James. Is that a magnet which is fixed to the bottom of the globe, and by means of which we set the globe in a proper direction with regard to the cardinal points, north, south, east, and west?

Tutor. That is called a compass, the needle of which, being rubbed by the natural or real magnet, becomes possessed of the same properties as

those which belong to the magnet itself.

Charles. Can any iron and steel be made magnetic?

Tutor. They may; but steel is the most proper for the purpose. Bars of iron or steel, thus prepared, are called *artificial magnets*.

James. Will these soon lose the properties thus obtained?

Tutor. Artificial magnets will retain their properties almost any length of time; and since they may be rendered more powerful than natural ones, and can be made of any form, they are generally used; so that the natural magnet is kept rather as a curiosity, than for any purposes of real utility.

Charles. What are the leading properties of the magnet?

Tutor. (1.) A magnet attracts iron. (2.) When placed so as to be at liberty to move in any direction, its north end points to the north pole, and its south end to the south pole: this is called the *polarity* of the magnet. (3.) When the *north* pole of one magnet is presented to the *south* pole of another, they will attract one another. But if the two *south*, or the two *north* poles, are brought together, they will repel each other. (4.) When a magnet is so situated as to be at liberty to move any way, the two poles of it do not lie in an horizontal direction, it inclines one of its poles towards the horizon, and, of course elevates the other pole above it; this is called the *inclination* or *dipping* of the magnet. (5.) Any magnet may be made

to impart its properties to iron and steel.

James. Does the inclination of the magnet show its natural direction?

Tutor. This magnetised, or dipping needle, is an instrument intended to show the natural direction of this important production of nature, at the particular place in which the instrument is situated.

CONVERSATION II.

Magnetic Attraction and Repulsion.

TUTOR. Having mentioned the several properties of the magnet or loadstone, I intend, at this time, to enter more particularly into the nature of magnetic attraction and repulsion.—Here is a thin iron bar, eight or nine inches long, rendered magnetic, and, on that account, it is now called an artificial magnet: I bring a small piece of iron within a little distance of one of the poles of the magnet, and you see it is attracted or drawn to it.

Charles. Will not the same effect be produced, if the iron be presented to any other part of the magnet?

Tutor. The attraction is strongest at the poles, and it grows less and less in proportion to the distance of any part from the poles; so that, in the middle, between the poles, there is no attraction, as you shall see by means of this large needle.

James. When you held the needle near the pole of the magnet, the magnet moved to that, which looks as if the needle attracted the magnet.

Tutor. You are right: the attraction is mutual, as is evident from the following experiment. I place this small magnet on a piece of cork, and the needle on another piece, and let them float on water, at a little distance from each other, and you

observe that the magnet moves towards the iron, as much as the iron moves towards the magnet.

Charles. If two magnets were put in this situation, what would be produced?

Tutor. If poles of the same name, that is, the two north, or the two south, be brought near together, they will repel one another; but, if a north and south pole be presented, the same kind of attraction will be visible, as there was between the magnet and needle.

James. Will there be any attraction or repulsion, if other bodies, as paper, or thin slips of wood, be placed between the magnets, or between the magnet and iron?

Tutor. Neither the magnetic attraction nor repulsion is in the least

diminished, or in any way affected, by the interposition of any kind of bodies, except iron. Bring the magnets together within the attracting or repelling distance, and hold a slip of wood between them: you see they both come to the wood.

Charles. You said that iron was more easily rendered magnetic than steel, does it retain the properties as long too?

Tutor. If a piece of soft iron, and a piece of hard steel, be brought within the influence of a magnet, the iron will be most forcibly attracted, but it will almost instantly lose its acquired magnetism, whereas the hard steel will preserve it a long time.

James. Is magnetic attraction and

repulsion at all like what we have sometimes seen in electricity?

Tutor. In some instances there is a great similarity: Example I. Tie two pieces of soft wire (Vol. VI, Plate II, Fig. 28 *) each to a separate thread, which join at top, and let them hang freely from a hook *x*. If I bring the marked or north end of a magnetic bar just under them, you will see the wires repel one another, as they are shown in the figure hanging from z.

Charles. Is that occasioned by the repelling power which both wires have acquired in consequence of being both rendered magnetic with the same pole?

Tutor. It is: and the same thing

* The reader must turn to Vol. VI, Plate II, for the figures referred to in Magnetism.

would have occurred if the south pole had been presented instead of the north.

James. Will they remain long in that position?

Tutor. If the wires are of very soft iron they will quickly lose their magnetic power; but if steel wires be used, as common sewing needles, they will continue to repel each other, after the removal of the magnet.

Example II. I lay a sheet of paper flat upon a table, and strew some iron filings upon it. I now lay this small magnet (Vol. VI, Fig. 29) among them, and give the table a few gentle knocks, so as to shake the filings, and you observe in what manner they have ranged themselves about the magnet.

Charles. At the two ends, or poles, the particles of iron form themselves into lines, a little sideways; they bend, and then form complete arches, reaching from some point in the northern half of the magnet, to some other point in the southern half.—Pray how do you account for this?

Tutor. Each of the particles of iron, by being brought within the sphere of the magnetic influence, becomes itself magnetic, and possessed of two poles, and, consequently, disposes itself in the same manner as any other magnet would do, and also attracts with its extremities the contrary poles of other particles.

Example III. If I shake some iron filings through a gauze sieve, upon a paper that covers a bar magnet, the

filings will become magnets, and will be arranged in beautiful curves.

James. Does the polarity of the magnet reside only in the two ends of its surface?

Tutor. No: one half of the magnet is possessed of one kind of polarity, and the other of the other kind: but the ends, or poles, are those points in which that power is the strongest.

DEFINITION. A line drawn from one pole to the other is called the axis of the magnet.

CONVERSATION III.

The Method of making Magnets—Of the Mariner's Compass.

TUTOR. I have already told you, that artificial magnets, which are made of steel, are now generally used in preference to the real magnet, because they can be procured with greater ease, may be varied in their form more easily, and will communicate the magnetic virtue more powerfully.

Charles. How are they made?

Tutor. The best method of making

artificial magnets is to apply one or more powerful magnets to pieces of hard steel, taking care to apply the north pole of the magnet or magnets to that extremity of the steel, which is required to be made the south pole, and to apply the south pole of the magnet to the opposite extremity of the piece of steel.

James. Has a magnet, by communicating its properties to other bodies, its own power diminished?

Tutor. No, it is even increased by it.—A bar of iron, three or four feet long, kept some time in a vertical position, will become magnetic, the lower extremity of it attracting the south pole, and repelling the north pole. But if the bar be inverted, the polarity will be reversed.

Charles. Will steel produce the same effects?

Tutor. It will not; the iron must be soft; and hence bars of iron, that have been long in a perpendicular position, are generally found to be magnetical, as fire irons, bars of windows, &c.—If a long piece of hard iron be made red hot, and then left to cool in the direction of the magnetical line, it usually becomes magnetical.

Striking an iron bar with a hammer, or rubbing it with a file, while held in this direction, renders it magnetical. An electric shock, and lightning, frequently render iron magnetic.

James. An artificial magnet, you say, is often more powerful than the real one: can a magnet, therefore,

communicate to steel a stronger power than it possesses?

Tutor. Certainly not: but two or more magnets, joined together, may communicate a greater power to a piece of steel, than either of them possesses singly.

Charles. Then you gain power according to the number of magnets made use of?

Tutor. Yes: very powerful magnets may be formed by first constructing several weak magnets, and then joining them together to form a compound one, and to act more powerfully upon a piece of steel.

The following methods are among the best for forming artificial magnets:—

1. Place two magnetic bars, A

and B (Vol. VI, Fig. 25), in a line, so that the north or marked end of one, shall be opposite to the south end of the other, but at such a distance, that the magnet C, to be touched, may rest with its marked end on the unmarked end of B, and its unmarked end on the marked end of A. Now apply the north end of the magnet L, and the south end of D, to the middle of C, the opposite ends being elevated as in the figure. Draw L and D asunder along the bar C, one towards A, the other towards B, preserving the same elevation: remove L D a foot or more from the bar, when they are off the ends, then bring the north and south poles of these magnets together, and apply them again to the middle of the bar C as before: the same process is to

be repeated five or six times, then turn the bar, and touch the other three sides in the same way, and, with care, the bar will acquire a strong fixed magnetism.

2. Upon a similar principle, two bars, A B, C D (Vol. VI, Fig. 26), may be rendered magnetic. These are supported by two bars of iron, and they are so placed that the marked end B may be opposite to the unmarked end D; then place the two attracting poles G I on the middle of A B, as in the figure, moving them slowly over it ten or fifteen times. The same operation is to be performed on C D, having first changed the poles of the bars, and then on the other faces of the bars; and the business is accomplished.

The touch thus communicated,

may be farther increased, by rubbing the different faces of the bars, with sets of magnetic bars, disposed as in Fig. 27.

James. I suppose all the bars should be very smooth.

Tutor. Yes, they should be well polished, the sides and ends made quite flat, and the angles quite square, or right angles.

There are many magnets made in the shape of horse-shoes; these are called horse-shoe magnets; and they retain their power very long by taking care to join a piece of iron to the end as soon as it is done with.

Charles. Does that prevent its power from escaping?

Tutor. It should seem so; the power of a magnet is even increased by suffering a piece of iron to remain

attached to one or both of its poles. Of course a single magnet should always be thus left.

James. How is magnetism communicated to compass needles?

Tutor. Fasten the needle down on a board, and draw magnets about six inches long, in each hand, from the centre of the needle outwards; then raise the bars to a considerable distance from the needle, and bring them perpendicularly down on its centre, and draw them over again, and repeat this operation about twenty times, and the ends of the needle will point to the poles contrary to those that touched them.

Charles. I remember seeing a compass, when I was on board the frigate that lay off Worthing, the

needle was in a box, with a glass over it.

Tutor. The mariner's compass consists of the box, the card or fly, and the needle. The box is circular, and is so suspended as to retain its horizontal position in all the motions of the ship. The glass is intended to prevent any motion of the card by the wind, the card or fly moves with the needle, which is very nicely balanced on a centre. It may, however, be noticed, that a needle, which is accurately balanced before it is magnetised, will lose its balance by being magnetised, on account of what is called the *dipping*, therefore a small weight, or moveable piece of brass, is placed on one side of the needle, by the shifting of which the needle will always be balanced.

It must be observed, that, in the construction of such instruments, neither iron, steel, nor other ferruginous matter, must be suffered to be in, or even near the frame, because a very small quantity of it is sufficient to render the observations of no value whatever.

CONVERSATION IV.

Of the Variation of the Compass.

CHARLES. You said, I think, that the magnet pointed *nearly* north and south: how much does it differ from that line?

Tutor. It rarely points exactly north and south, and the *deviation* from that line is called the *variation of the compass*, which is said to be east or west.

James. Does this differ at different times?

Tutor. It does; and the variation is very different in different parts of the world. The variation is not the same now that it was half a century ago, nor is it the same now at London that it is at Bengal or Kamtschatka. The needle is continually traversing slowly towards the east and west.

This subject was first attended to by Mr. Burrowes, about the year 1580, and he found the variation then, at London, about 11° 11′ east. In the year 1657 the needle pointed due north and south: since which the variation has been gradually increasing towards the west, and in the year 1803 it was equal to something more than 24° west, and was then advancing towards the same quarter.

Charles. That is at the rate of

something more than ten minutes each year.

Tutor. It is, but the annual variation is not regular; it is more one year than another. It is different in the several months, and even in the hours of the day.

James. Then, if I want to set a globe due north and south, to point out the stars by, I must move it about till the needle in the compass points to 24° west?

Tutor. Just so: and mariners, knowing this, are as well able to sail by the compass as if it pointed due north.

Charles. You mentioned the property which the needle had of *dipping*, after the magnetic fluid was communicated to it: is that always the same?

Tutor. It probably is, at the same place: it was discovered by Robert Norman, a compass maker, in the year 1576, and he then found it to dip nearly 72°, and, from many observations made at the Royal Society, it is found to be the same.

James. Does it differ in different places?

Tutor. Yes: in the year 1773, observations were made on the subject, in a voyage toward the north pole; and from these it appears, that,

In latitude	60°	18′	the dip was	75°	0′
———	70	45	———	77	52
———	80	12	———	81	52
———	80	27	———	82	2½

I will show you an experiment on this subject. Here is a magnetic bar, and a small dipping needle: if I

carry the needle, suspended freely on a pivot, from one end of the magnetic bar to the other, it will, when directly over the south pole, settle directly perpendicular to it, the north end being next to the south pole. As the needle is moved, the dip grows less and less, and, when it comes to the magnetic centre, it will be parallel to the bar; afterwards, the south end of the needle will dip, and, when it comes directly over the north pole, it will be again perpendicular to the bar.

The following facts are deserving of recollection.

1. Iron is the only body capable of being affected by magnetism.

2. Every magnet has two opposite points called *poles*.

3. A magnet, freely suspended, ar-

ranges itself, so that these poles point nearly north and south. This is called the *directive property*, or polarity of the magnet.

4. When two magnets approach each other, the poles of the *same names*, that is, both north, or both south repel each other.

5. Poles of different names attract each other.

6. The loadstone is an iron ore, naturally possessing magnetism.

7. Magnetism may be communicated to iron and steel.

8. A steel needle rendered magnetic, and fitted up in a box, so as to move freely in any direction, constitutes the mariners' compass.

Charles. I think there is a similarity between electricity and magnetism.—See Vol. VI.

Tutor. You are right; there is a considerable analogy, and a remarkable difference also between magnetism and electricity.

Electricity is of two sorts, positive and negative: bodies possessed of the same sort of electricity repel each other, and those possessed of different sorts attract each other.—In Magnetism, every magnet has two poles; poles of the same name repel each other, and the contrary poles attract each other.

In Electricity, when a body, in its natural state, is brought near to one that is electrified, it acquires a contrary electricity, and becomes attracted by it.—In Magnetism, when an iron substance is brought near one pole of a magnet, it acquires a

contrary polarity, and becomes attracted by it.

One sort of electricity cannot be produced by itself. In like manner, no body can have only one magnetic pole.

The electric virtue may be retained by electrics, but it pervades conducting substances. The magnetic virtue is retained by iron, but it pervades all other bodies.

On the contrary: the magnetic power differs from the electric, as it does not affect the senses with light, smell, taste, or noise, as the electric does.

Magnets attract only iron; but the electric fluid attracts bodies of every sort.

The electric virtue resides on the

surface of electrified bodies, but the magnetic is internal.

A magnet loses nothing of its power by magnetising bodies, but an electrified body loses part of its electricity by electrifying other bodies.

END OF THE FIFTH VOLUME.

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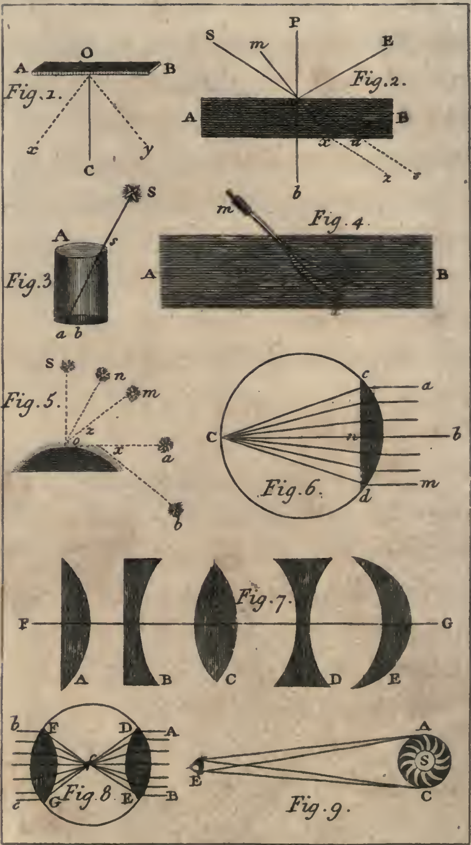

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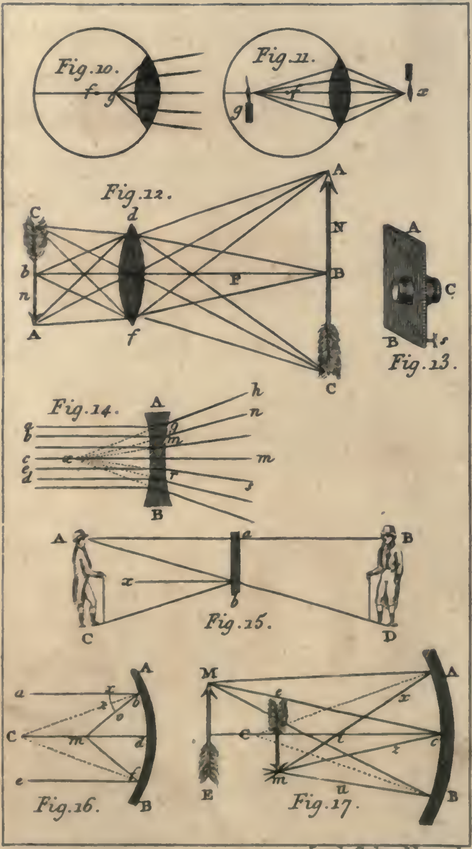

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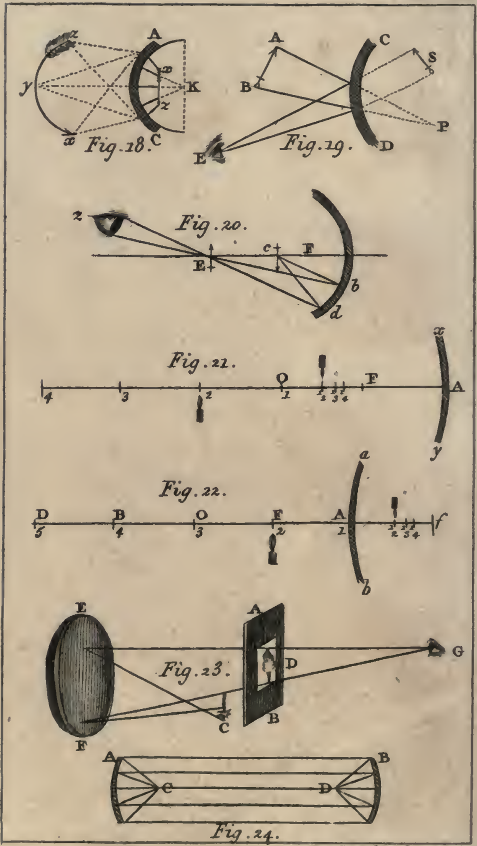

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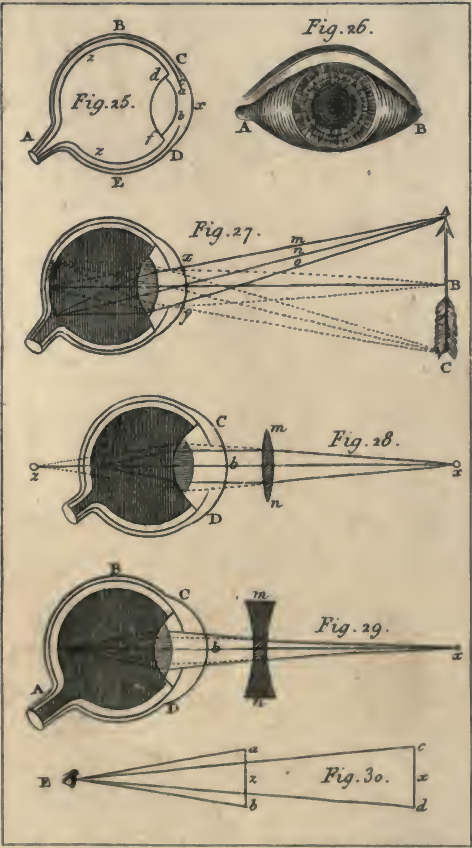

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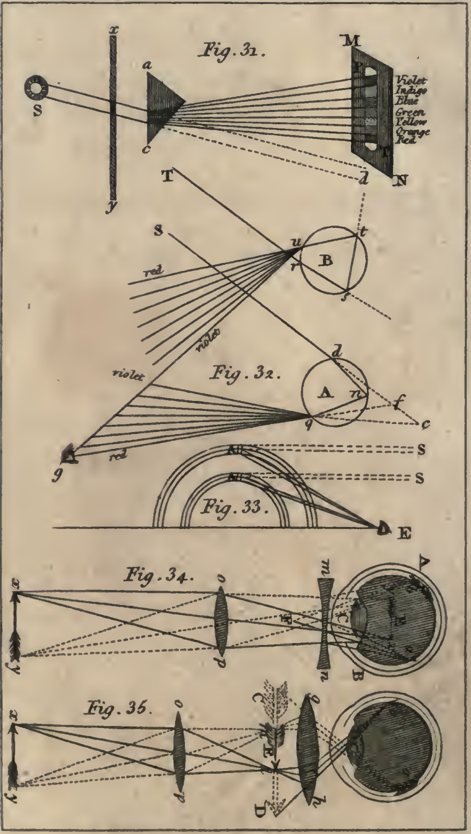

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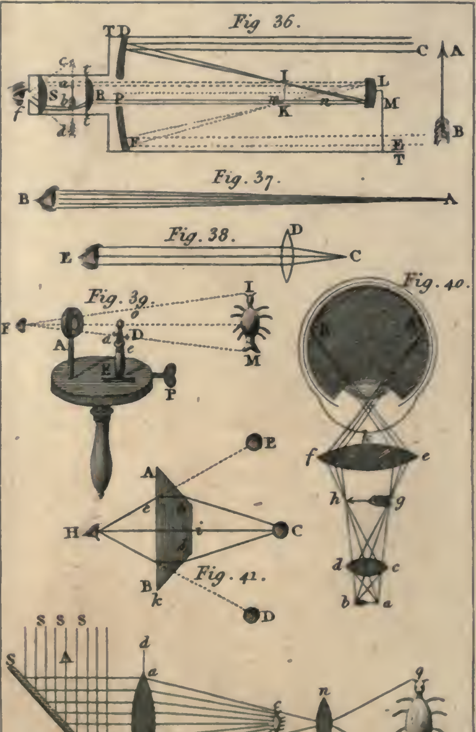

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